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Classical and conservation biological control of pest insects within prairie and crop systems

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Chapter I

General Introduction and Literature Review

Thesis Organization

This thesis is organized into four chapters. Chapter one begins with a literature review containing a general introduction, which provides a review of classical and conservation biological control in annual crop and perennial vegetation systems to reduce pest populations, specifically the soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphididae). Chapter two reports the results of field release trials of the parasitoid wasp *Binodoxys communis* as a biological control agent of the soybean aphid, as well as its preferences for certain initial aphid densities. Chapter three details the benefits of incorporating perennial vegetation strips into crop systems to improve the abundance of natural enemy populations, as well as its effect on pest and pollinator abundance and diversity. Chapter four is a short summary of the experimental findings and conclusions.

Introduction and Literature Review

Nearly 40% of insect pests were introduced into the US (Pimentel 1993), resulting in approximately $936 million in US crop losses, and $1.2 billion in pesticide application in the US each year (Pimentel 2001). Prior to the discovery of the soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphididae) in the Midwest July of 2000 (Ragsdale et al. 2004), soybean [*Glycine max* (L.) Merr.] fields in the US required less than 1% of insecticidal intervention (Fernandez-Cornejo and Jans 1999), in contrast with 16% in 2006 (NASS/USDA 2007). In 2003 alone, over 42 million acres of soybean in the Midwest were infested with *A. glycines,* and over 7 million acres were treated with insecticides (Landis et

al. 2003). The use of insecticides to manage *A. glycines* populations has proven to be effective when used in conjunction with scouting and proper application timing (Myers et al. 2005). However, the overuse of broad-spectrum insecticides may lead to problems such as developed resistance to the active ingredient, resurgence of *A. glycines*, and replacement of *A. glycines* by another insect species that did not previously hold significant pest status (Stern et al. 1959). The latter two consequences are due to the knockdown of natural enemy populations that may have otherwise kept insects from reaching pest status. Synthetic insecticides are effective; however, the end result of their abuse can be devastating (Carson 1962, Pimentel 2005 and references therein). Negative impacts of pesticides on human health, the environment, and the development of resistant insects have provided a need for the implementation of alternative methods to manage invasive species (OTA 1995) such as *A. glycines.*

Whether or not an introduced species becomes invasive may be due to a multitude of factors (enemy release hypothesis, climatic variables, selection for 'invasive' genotypes, human disturbance, etc.) (Colautii et al. 2004). The enemy release hypothesis (Keane and Crawley 2002, Torchin et al. 2002, 2003; Mitchell and Power 2003, Hajek 2004) suggests that the escape of *A. glycines* from co-evolved natural enemies present in its native range in Asia (Liu et al. 2004, Wu et al. 2004, Miao et al. 2007) contributed heavily to the proliferation and ultimate pest status in the US (i.e., introduced exotic biological control organisms) functions to reunite natural enemies of pest species in order to restore the balance that should exist in natural ecosystems. *Binodoxys communis* (Gahan) (Hymenoptera: Braconidae) was approved for field release experiments in 2007 out of several parasitoid wasps as a potential biological control organism of *A. glycines* (Wyckhuys et al. 2007). The

establishment of classical biological control programs is dependent on a number of factors including, but not limited to: the ability of the biological control organism to seek out and aggregate near the target pest; adaptation to local climate and the ability to survive the winter; short development time relative to that of the target pest; life cyle synchronization with that of the host; narrow host range; successful establishment; and the ability of the biological control agent to disperse well (Hajek 2004). Optimal conditions for the proliferation of introduced biological control organisms are difficult to obtain, although optimal ecological conditions may be obtained through the manipulation of non-crop habitat within and surrounding crop systems (Barbosa 1998). Integration of perennial plants into crop systems or buffer strips has been shown to improve the impact of pest suppression indirectly by providing resources necessary for the sustainability of introduced biological control organisms and resident natural enemies (Landis et al. 2000). The suitability of *B. communis* as a biological control organism of *A. glycines*, and the potential of conservation biological control via habitat management, restoration, and landscape design are evaluated in the following sections.

Aphis glycines biology

Aphis glycines is native to Asia, where its secondary (summer) host is cultivated soybean, *Glycine max* (L.) Merr. (Blackman and Eastop 2000). Wang et al. (1994) notes that *A. glycines* is only an occasional pest in China and other parts of Asia, but plants colonized by *A. glycines* in the early vegetative growth stage, may experience substantial yield loss exceeding 50% (Wang et al. 1994). In addition to reduction of seed yield, *A. glycines* can also reduce seed quality (e.g., discoloration, deformation), which is an economic loss for

food-grade soybean growers and in production of organic soybean. By 2004, the aphid was found in 24 states and three Canadian provinces (Losey et al. 2002, Ragsdale et al. 2004, Rutledge et al. 2004), allowing the spread of harmful soybean viruses such as alfalfa mosaic virus, soybean dwarf virus, and soybean mosaic virus (Iwaki et al. 1980, Clark and Perry 2002, Wang et al. 2006).

Aphis glycines is a heteroecious holocyclic species (host-alternating, with sexual reproduction during part of its life cycle). The primary (overwintering) host of *A. glycines* in North America consists of various buckthorn (*Rhamnus)* species, namely *R. cathartica* L. and *R. alnifolia* L'Hér (Voegtlin et al. 2004). The life cycle of *A. glycines* begins on *Rhamnus* in the spring, as eggs emerge from diapause in a cascade of events that seems to be triggered by plant hormonal cues (Dixon 1976) and heat units acquired by the eggs (Bahlai et al. 2007), leading to their first wingless generation known as fundatricies. Each subsequent generation is produced parthenogenically until the fall, when the aphids enter into their overwintering stage once again (Ragsdale et al. 2004). The second generation is also composed of mostly wingless morphs (apterae), but the third generation consists primarily of winged morphs (alatae), which emigrate in search of its secondary (summer) host, cultivated soybean (Voegtlin et al. 2004). *Aphis glycines* is capable of producing 18 overlapping generations per year (Wang et al. 1962), each aphid potentially giving rise to over 70 offspring of either winged or wingless morphs in optimal conditions (McCornack et al. 2004). McCornack et al. (2004) found that the optimal temperature for *A. glycines* development is 27.8°C, in which mean developmental time was 4.5 days (time from birth to first reproduction). The result of such a rapid development rate coupled with optimal environmental conditions may lead to populations of *A. glycines* doubling in less than two

days. In the fall, soybean plants entering senescence give rise to winged females (gynoparae) which emigrate in search of *Rhamnus,* and produce nymphs that develop into sexual oviparae. The pheromone (1*R*,4a*S*,7*S*,7a*R*)-nepetalactol released by oviparae attracts winged males produced on soybean to *Rhamnus* (Zhu et al. 2006). The males then mate with the oviparae, which in turn lay overwintering eggs on *Rhamnus*, commonly at the interface between the bud and the twig near the time of leaf drop.

Bahlai et al. (2010) found that *A. glycines* density was positively correlated with the density of buckthorn, concluding that the most important factor in determining whether a soybean field is likely to be colonized by *A. glycines* in a low aphid year was the presence of buckthorn (Bahlai et al. 2010). The movement of *A. glycines* from one field to another has been attributed to crowding, which stimulates apterous adults to produce a higher proportion of alatoid offspring (Lu and Chen 1993). The combination of parthenogenic reproduction, a high reproductive rate, and favorable environmental conditions can result in logarithmic population growth of *A. glycines* within soybean fields (Takahashi et al. 1993). Population growth at or above the the economic injury level of 674 aphids per plant (Ragsdale et al. 2007) can result in a number of costs to plant health such as reduced photosynthesis, (Macedo et al. 2003), reduced number of branches, stunting, withered or shed flowers, and reduced pods (Wang et al. 1962). Heavily infested soybean plants above the economic threshold injury level are subject to sooty mold growth, and an increased probability of receiving various plant viruses, such as soybean mosaic virus and alfalfa mosaic virus (Hill et al. 2001). *Aphis glycines* was able to escape its native natural enemies in Asia within the US, but by reuniting *A. glycines* with a suitable natural enemy native to Asia, the chances of controlling *A. glycines* are greatly improved.

Resident natural enemies in the US and China

The natural enemy guild preying on *A. glycines* within the North-Central US is mainly comprised of generalist predators. Over 85% of these natural enemies consist of *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) and *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), which generally respond to high aphid populations that may arrive late in the season (Rutledge et al. 2004, Costamagna and Landis 2006). This means that generalist predator species often times only results in the reduction of *A. glycines* populations after it has reached economically damaging levels, as was shown with *H. arculata* predation on *A. glycines* (van den Berg et al. 1997). In order to prevent economically damaging populations of *A. glycines*, it is important that natural enemy guilds contain biological control organisms that arrive early in the season, when *A. glycines* populations are below the economic threshold. Specialist parasitoids with narrow host ranges are known to suppress *A. glycines* populations in China, when aphid pressure is low. In Asia, generalist predators are important in the reduction of *A. glycines* populations, although much of the early season suppression of *A. glycines* is due to parasitoid wasps (Liu et al. 2004) that are nearly absent from the natural enemy guilds present in the North-Central US (Kaiser et al. 2004, Rutledge et al. 2004, Costamagna et al. 2008, Noma and Brewer 2008). The presence of parasitoids is more directly linked with the response of the parasitoid to the environment in which hosts would likely be found in many systems, thus providing early season protection of *A. glycines* outbreaks. This form of biological control would complement the present natural enemy guilds within the North-Central US, and provide more lasting control of *A. glycines* populations.

In China, fifteen parasitoid species have been shown to be very important in the reduction of *A. glycines* populations (Liu et al. 2004, Wu et al. 2004, Miao et al. 2007), in contrast to the three individual *A. glycines* attacked by parasitoid wasps in Indiana (Rutledge et al. 2004); two genera in New York, *Aphidius* and *Proan* spp. (Nielsen and Hajek 2005); six species recovered in Michigan, *Aphelinus asychis, Aphelinus varipes* complex, *Aphidius colemani, Binodoxys kelloggensis, Lysiphlebus testaceipes,* and *Proan* sp. (Noma and Brewer 2008), each coinciding with very low levels of parasitism. To complement current natural enemy guilds in the US, it was necessary to seek out biological control agents from Asia to reunite with *A. glycines* attuned to low aphid densities, and dependent on *A. glycines* for biological support (Heimpel et al. 2004b). To date, 35 populations consisting of at least 14 species of parasitoids from several areas of northeast China, Korea, and Japan have been received and successfully established in quarantine at the USDA/ARS lab in Newark, Delaware. This includes seven new populations in five species collected June-July of 2007. Species maintained in quarantine at the USDA/ARS lab include *Aphelinus* spp., *Lipolexis gracilis, Aphidius* spp., *Trioxys* spp., *Diaretiella* spp., *Binodoxys communis*, and *Binodoxys koreanus* Starý (Desneux et al. 2009b). Based on host specificity evaluations, the following parasitoid species have been considered for release: two species of *Binodoxys* (*B. communis,* and *B. koreanus*); two populations in the *Aphelinus-varipes* complex; and two populations of *Aphelinus-mali* complex (Wyckhuys et al. 2007). *Binodoxys communis* was approved for release in 2007, and its success as a biological control agent of *A. glycines* is evaluated in Chapter 2 of this thesis.

For a parasitoid wasp to be considered for biological control, it must first meet several criteria: 1) it must have a narrow host range; 2) display adequate host searching

abilities; and 3) high fecundity (DeBach and Rosen 1991). Mahr et al. (2008) elaborate further on attributes which contribute to lasting biological control, such as (1) having a well synchronized life cycle with the pest; (2) having a short developmental time relative to the pest; (3) the ability to disperse well; (4) exhibit host-feeding behavior; and (5) being well adapted to the local climate, including the ability to overwinter.

Classical biological control and *Binodoxys communis* biology

Although the literature of *B. communis* life history and physiological adaptations are sparse, much of the research conducted on aphid parasitoids in general, and current research to obtain information about the host range of this species has proved useful. Liu et al. (2004) characterizes *Binodoxys* as a genus within the family Aphidiidae, although *B. communis* is not listed. *Trioxys communis* (Gahan 1926) is listed as a parasitoid wasp of the cotton aphid, *Aphis gossypii*. Although most literature from American authors list *Binodoxys* as a genus within the family Braconidae, belonging to the subfamily Aphidiinae. *Binodoxys communis* primarily parasitizes aphids within the genus *Aphis* that are not protected by endosymbionts, aphid-tending ants, or host-plant associations. Of the species that *B. communis* accepts for oviposition, successful parasitism is restricted by behavioral and physiological incompatibility of some host species as well as resistance incurred through association with toxic host plants and endosymbionts. Desneux et al. (2009a) concludes that *B. communis* has a narrow host range for *A. glycines*, although the study also reveals the willingness of *B. communis* to attack several aphids within the genus *Aphis*, including *A. nerii*, which resulted in no adult emergence. The tendency of *B. communis* to devote handling time and oviposition to unsuitable hosts wastes time as well as eggs, thus reducing their potential to suppress *A.*

glycines populations. Some parasitoids may exhibit high fidelity in their response to volatiles, with genetically based preferences (Reed et al. 1995, Vaughn et al. 1996, Rodriguez et al. 2002). Wyckhuys and Heimpel (2007) found that *B. communis* emerging into active *A. glycines* colonies are likely to reinforce their association with this host-plant compounds (HPCs), but cannot distinguish between odors from *A. glycines* host plant compounds, and non-target HPCs. This finding further suggests the potential risk for attack of non-target organisms, but not without mentioning the preference and need of *B. communis* for alternative sugar sources.

Floral nectar, extra-floral nectar, and honeydew are regularly exploited by parasitoids (Gilbert and Jervis 1998, Singh et al. 2000, Heimpel et al. 2004a, Lee et al. 2006). The suitability of these foods is dependent on the species-specific degree of gustatory acceptance and metabolism of these compounds (Olson et al. 2000, Hausmann et al. 2005, Wäckers et al. 2006, Winkler et al. 2005, Chen and Fadamiro 2006). The lack of suitable sugar sources lowers the net reproductive success of a parasitoid below the threshold able to maintain populations, despite adequate availability of hosts (Winkler et al. 2006). Availability of non-host food sources, therefore enhances parasitoid fitness (or population size), likely increasing the rate of parasitism, and thus reducing host populations (Wäckers et al. 2008). Van Rijn and Sabelis (2005) suggest that the greatest impact on host population reduction is expected when both host searching rate and reproductive life span is enhanced by nectar feeding. Wyckhuys et al. (2008) found that honey is of greater nutritional value for *B. communis* than honeydew. Furthermore, since honeydew appears to be nutritionally inferior to other foods for *B. communis*, habitat management tactics to increase the availability of nectar sources are likely to increase host searching rate and reproductive life span.

Habitat management providing for exposed floral nectar, or other possible sugar sources near soybean fields in which *B. communis* is released could aid in the establishment and efficacy of *B. communis* in *A. glycines* biological control efforts (Gurr and Wratton 1999, van Lenteren et al. 2006).

Conservation biological control

Early season predation is a major factor influencing *A. glycines* suppression within soybean fields, although factors present within agroecosystems make it difficult for natural enemies to maintain stable preventive fronts against *A. glycines* colonization. Frequent disturbances (i.e., tillage, pesticide application, and harvesting) within crop systems require recolonization of natural enemies (Wissinger 1997). Numbers and activity of aphid parasitoids may be prompted in agricultural systems through provision of missing resources such as alternate or supplementary foods and critical habitat needed in reproduction or overwintering (Pickett and Bugg 1998; Landis et al. 2000). Protection and conservation of aphid parasitoids can be achieved via orchard undergrowth management, shade trees, weeds, intercropping, mixed cropping, strip farming, etc. (Staŕy 1970, Bao and Gu 1998). Landscape diversity and composition surrounding soybean fields contributes to biological control services provided by generalist predators (Gardiner et al. 2009). In general, greater landscape diversity, especially comprised of forested habitat, favor suppression of *A. glycines.* In a study conducted by Noma et al. (2010), greater habitat diversity was correlated with lower aphid densities.

Biological control efforts to release natural enemies of pest insects have been difficult to implement, and often unsuccessful. Only 11.2% of the attempted introductions of

parasitoids and predators against insect pests have resulted in complete control (Hajek 2004). Frequently, natural enemy populations are unsustainable due to limited refuge and resources following crop rotation, tillage, spraying broad-spectrum insecticides, among other management practices. Conservation biological control serves to resolve many of the shortcomings of biological control by manipulating the environment in order to provide a more suitable ecological infrastructure for natural enemies (Barbosa et al. 1998). These conservation practices are meant to be practical tools in which farmers can implement on their land, in order to support natural enemy populations, without generating economic distress or sacrificing yield.

Objectives

In the summers of 2007, 2008, and 2009. I studied the success of *Binodoxys communis* field releases within cultivated soybean fields infested with the soybean aphid, and the abundance of natural enemies in reconstructed prairie integrated within annual row-crop systems. The objectives were as follows:

Chapter two objectives:

1.) Determine the success of *Binodoxys communis* field releases within soybean fields infested with *Aphis glycines*.
2.) Determine if the initial density of *A. glycines* has a direct, or inverse relationship with parasitism levels of *B. communis.*

Chapter three objectives:

1.) **Determine the effect of perennial plant coverage restored within annual crop systems on the community structure of natural enemies, pests, pollinators, and incidental arthropods.**
2.) **Determine how varying proportions and distributions of perennial plant coverage affect the abundance of arthropods.**

Chapter two provides:

- Release techniques used for the imported parasitoid wasp *B. communis*, on *A. glycines* populations.
- Information on the success of colonization efforts in releasing *B. communis*.
- Information on the ability of *B. communis* to colonize within *A. glycines*-infested soybean fields, and suppress *A. glycines* populations.
- The impact of high and low *A. glycines* densities on the fecundity and survivability of *B. communis* when released within exclusion cages, as well as the parasitoid's preference toward high and low aphid densities once allowed to disperse throughout *A. glycines*-infested soybean fields.

Chapter three provides:

- Lists of natural enemies, pests, pollinators, and incidental arthropods present within prairie, soybean, and corn land cover at the Neal Smith National Wildlife Refuge collected in Jasper County, Iowa in 2009 and 2010, as well as their diversity in each land cover type.

- The effect of land cover type on the abundance natural enemies, pests, and pollinators.
- The effect of varying proportions and distributions of restored prairie treatments on the abundance of natural enemies, pests, and pollinators within crop and prairie land cover.

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Chapter II

Binodoxys communis (Hymenoptera: Braconidae): pitfalls and strengths of a promising candidate for biological control of the soybean aphid, *Aphis glycines*

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Abstract

Since its introduction in North America, the soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphididae) has become the primary pest of soybean in North America. Despite the impact of predators commonly found in North American soybean fields, frequent pest outbreaks within soybean mandate the use of insecticides to prevent crop injury. Aphid parasitoid wasps such as *Binodoxys communis* (Gahan) (Hymenoptera: Braconidae) have been shown to be very important in Chinese soybean fields for early-season aphid suppression, while parasitoids comprise a small fraction of the North American natural enemy guilds. From 2008 to 2010, we released *B. communis* at five research farms throughout Iowa to measure the effects of releases on aphid populations, and to describe the capacity of *B. communis* to effectively locate and colonization aphid host-patches. Paired caged treatments were utilized to provide a baseline comparison of aphid populations over time with and without the addition of *B. communis*, while open plots allowed for comparison

of environmental factors, including how other natural enemies could affect aphid populations. Aphid densities were more aggressively controlled by abiotic and biotic factors in the environment than by *B. communis*, and that aphid densities were not statistically different in cages that were inoculated with *B. communis*. In 2009 and 2010, the impact of host density on parasitism levels of *B. communis* was measured. At high aphid densities typical to late-season aphid populations, *B. communis* acted in a density-independent manner. There may be potential for this biological control organism to be used in augmentative biological control early in the season.

KEYWORDS: *Aphis glycines*, soybean aphid, classical biological control, *Binodoxys communis*, parasitoid wasp, Aphidiinae, host density

Introduction

The soybean aphid *Aphis glycines* Matsumura (Hemiptera: Aphididae), is the most important pest of soybean, *Glycine max* (L.), in North America (US) (Ragsdale et al. 2010). Prior to the discovery of this pest during the 2000 growing season (Wedburg 2000), less than 0.1% of soybean acreage was treated with insecticides, compared with 13% of soybean acreage treated in 2006 (NASS/USDA 2007). Feeding damage caused by soybean aphid can decrease soybean yields as much as 40% in the US (DiFonzo and Hines 2002) and range from 50-70% (Wang et al. 1994) when populations are particularly high. Yield losses can be incurred directly, by reducing pod set and the number of seeds within pods at maturity (Beckendorf et al. 2008, Ragsdale et al. 2007, Rhainds et al. 2007), or indirectly, by vectoring plant pathogens such as alfalfa mosaic virus and soybean mosaic virus (Iwaki et al. 1980, Clark and Perry 2002, Wang et al. 2006).

Despite widespread colonization of soybean by the soybean aphid in southeast Asia, it is considered a pest of minor economic importance (Hill 1983). In China, economically damaging levels requiring insecticide applications for optimal yield are relatively infrequent (Liu et al. 2004) compared to North America. This suggests that native natural enemies of the soybean aphid play an important role in controlling its population (Miao et al. 2007, Liu et al. 2004). Predators can be found attacking the soybean aphid in North America and Asia (Fox et al. 2004, 2005, Rutledge et al. 2004, Costamagna and Landis 2006, Mignault et al. 2006, Kaiser et al. 2007, Noma and Brewer 2008, Schmidt et al. 2007, 2008, Meihls et al. 2010); however, specialist parasitoids of the soybean aphid are missing from the guild of soybean aphid natural enemies in North America (Rutledge et al. 2004, Schmidt et al. 2008). Miao et al. (2007) found that the combined effect of 13 predator species (mainly Coccinellidae, *Orius similis,* Syrphidae, Chrysopidae, and Linyphiid spiders) and three parasitoid species (*Lysiphlebus* sp., *Binodoxys communis* (Gahan) and *Aphelius* sp.) were key in limiting the rate of increase and abundance of soybean aphid populations (Miao et al. 2007). They found that parasitized aphids were more common than predators, and the rate of increase of soybean aphids was negatively correlated with the total density of parasitized aphids. Despite evidence that indigenous natural enemies can suppress soybean aphid populations (Fox et al. 2004, Rutledge and O'Neil 2005, Harwood et al. 2007), outbreaks continue to occur throughout North America (Johnson et al. 2008, Gardiner et al. 2009). Heimpel et al. (2004) has suggested that the pest status of the soybean aphid could be reduced if a parasitoid were established within North America that compliments the indigenous generalist natural enemy community.

In 2007, the parasitoid wasp *B. communis* was approved for release against the soybean aphid (Wyckhuys et al. 2007). *Binodoxys communis* was imported from provinces within China known to exhibit climatic similarity to the North-Central US (Desneux et al. 2009c). Many laboratory and field studies have explored various features of *B. communis* biology and ecology in North America, including but not limited to: intraguild predation (Chacón and Heimpel 2010), varying food sources on longevity (Wyckhuys et al. 2008), factors influencing egg load (Dieckhoff and Heimpel 2010), handling time and cryptic species of *B. communis* (Desneux et al. 2009a,b), and host suitability (Desneux et al. 2009b). These studies suggest that *B. communis* is capable of utilizing soybean aphids as a host in North America; however, it is not yet clear whether *B. communis* will colonize soybean aphid-infested soybean fields in Iowa, and serve as an effective biological control agent of soybean aphids. Despite the usefulness of laboratory studies in predicting the success of parasitoid introductions for biological control, an introduction provides the only real test of the species' true utility in the field (Hassell and Varley 1969). Murdoch et al. (1985) summarizes the most valuable features that a natural enemy should have in order to provide successful biological control including factors that have already been confirmed such as high host-specificity, synchronization with the host, and few hosts needed to complete its life cycle; what is not known is if *B. communis* has a high searching ability, or if it can increase in density rapidly when the host does. Functional response studies are designed to test whether the parasitoid is density dependent (responds to increasing levels of parasitism with increased host density), or density independent.

This research investigates the success of colonization and suppression of the soybean aphid by the Asian imported parasitoid wasp, *B. communis* within Iowa soybean fields. The

goal of this research was to characterize the level of soybean aphid suppression exhibited by *B. communis*, as it relates to factors such as geographic location and the initial density of aphids upon arrival of *B. communis*. Our objectives were as follows: 1) examine the success of *B. communis* colonization within soybean aphid-infested soybean fields throughout Iowa; 2) determine if *B. communis* can reduce or limit *A. glycines* populations within Iowa soybean fields; and 3) examine the relationship between initial aphid density, and parasitism levels. Our specific hypotheses were: 1) aphid populations would be significantly lower within un-caged controls compared to caged treatments; 2) aphid populations would be lower within *B. communis* caged release plots versus caged non-release plots; and 3) a greater number of aphids would be parasitized when initial aphid populations are high.

Materials and Methods

Parasitoid Colony. Detailed specifics of the origins, collection, and quarantine of *B. communis* are presented in Desneux et al. (2009c). Briefly, *B. communis* were collected from northeast China and South Korea in 2002 and 2003, respectively. Two *B. communis* colonies (n=20) were established on 30 May 2008, from greenhouse-reared individuals obtained from the University of Minnesota and maintained on soybean aphid-infested soybean plants within four separate growth chambers (25°C, 75% RH, and a photoperiod of 14:10 h [L:D]). Each pot contained three aphid-infested soybean plants, and was secured with fine mesh to contain aphids and wasps.

In 2009, a single *B. communis* colony (obtained from lab-reared colonies from the University of Minnesota) was established on 15 May 2009 from approximately 150 parasitized soybean aphids (herein mummies) collected from Harbin, China, and

approximately 50 mummies collected from Langfang, China. Clipped soybean leaves containing live aphids and parasitized aphids were placed directly onto V1-V3 soybean plants within insect rearing cages (47.5 x 47.5 x 47.5 cm; 'BugDorm,' MegaView Science, Taichung, Taiwan). Each cage consisted of twelve pots (9 cm x 9 cm x 10 cm) containing three soybean plants. Soybean plants were infested with approximately 20-100 non-parasitized aphids per plant at least three hours prior to the addition of newly emerged wasps. *Binodoxys communis* colonies were maintained by transferring approximately 200 newly emerged wasps to fresh cages using a mouth aspirator padded with cotton. Greenhouse conditions were maintained at 25°C, 75% RH, and a photoperiod of 16:8 (L:D) h.

Soybean Aphid Colony. Soybean aphids were obtained from a laboratory colony at Iowa State University. The colony was established from field-collected aphids found on soybean in Jasper and Story counties in 2008. Additional field-collected aphids were added in 2009 from Story County. Aphids were maintained in a growth chamber (25°C, 75% RH, and a photoperiod of 14:10 h [L:D]) on soybean aphid susceptible variety of soybean (Prairie Brand 2636NRR). Lab colony aphids were transferred to outdoor aphid rearing enclosures in early June to generate large populations for various experiments, of which ours was one. Rearing enclosures measured 4.5 m by 2.4 m and were planted with IA 3027 soybean seed in 30 cm rows. A fine mesh fabric stretched over a 2.4 m tall PVC pipe frame covered each enclosure. The fabric was buried under the soil line to exclude predators from entering the aphid rearing enclosures.

Field Sites and Experimental Design. We conducted two separate experiments during the 2008, 2009 and 2010. Experiments were conducted at multiple Iowa State

University research and demonstration farms (sites) to represent the majority of variation in abiotic and biotic factors, which may affect successful colonization of *B. communis* within Iowa. Sites were located in O'Brien County (Northwestern Iowa, referred to as the 'NW' site), 42°55′ N, 95°28′ W; Hancock County (Northern Iowa, referred to as the 'N' site), 42°56′ N, 93°48′ W; Lucas County (Southern Iowa, referred to as the 'S' site), 41°16′ N, 94°27′ W; Adair County (Southeastern Iowa, referred to as the 'SE' site), 40°58′ N, 93°18′ W; and Boone County (Central Iowa, referred to as the 'C' site), 42° 0′ N, 93°47′ W. All releases were conducted within conventionally managed soybean fields, excluding both seed and foliar applied insecticides. Soybean rows were spaced 76 cm. Sites that were utilized multiple years for the same study were conducted within different fields, but were conducted within 1 km in subsequent years.

Field Release Trials. In 2008, four sites were utilized for this experiment, and three sites were utilized in 2009 and 2010 (Fig. 1). The experiment was conducted within a 50 m by 5 m area of soybean in a randomized complete block design. The experimental unit (plot) consisted of four consecutive soybean plants within a single row of soybean. There were four blocks of three treatments for a total of 12 experimental units per site. Plots were spaced 1.5 m within a single row in each block; blocks were at least 6.1 m from the edge of the field, spaced 6.1 m apart within a single row, and at least 3.8 m apart traversing rows (across 5 rows, with 76 cm row spacing) (Fig. 2). Plots were spaced further apart in 2008 (5.2 m to 6.4 m apart); but plots were spaced 1.5 m apart in 2009 and 2010 to standardize the release technique for each site.

Aphid Density Study. This experiment was conducted at two sites in 2009 and 2010 (Fig. 1), utilizing a 50 m by 5 m area of soybean in a randomized complete block design, with four consecutive soybean plants representing the experimental unit (plot). There were five blocks each containing four treatments for a total of 20 experimental units per site. Each block was spaced 5.2 m apart, and at least 3.8 m from the edge of the field. Within each block, treatments that contained wasps were spaced closer to interior cages that did not contain wasps in order encourage the inner movement of adult wasps upon cage opening (Fig. 3).

Cage Construction, Aphid and Parasitoid Inoculation. Since both studies utilized cages in their treatment design, cages were constructed in the same fashion; however, the number of cages used, and the number of aphids and wasps added to each plant varied for each study, as will be detailed in their respective sections. Cages were constructed from tomato cages covered with white transparent no-see-um mesh (Balson-Hercules, New York, NY). Nets were sewn with two open ends, which were draped over 0.6 m diameter by 1.5 m tall tomato cages enclosing four soybean plants. The netting was buried approximately 0.9 m below the soil surface surrounding the caged, and closed at the top with a 27 gauge plastic-coated flexible wire. Four adjacent soybean plants were removed from each side of the plot to make room for the cage. Cages were employed to facilitate the establishment of aphids and *B. communis* by preventing aphids from leaving plots, and excluding natural enemies while the wasp completed its first generation within the field. Open field plots unique to the field release trials were marked with a flag, and four consecutive plants were infested with aphids.

Four adjacent plants were then removed from each side in order to distinguish the experimental plot from the rest of the row.

Due to seasonal variation in soybean aphid abundance, aphid populations were artificially established for *B. communis* field release trials, and purposefully added at various densities and dates for the aphid density study. Apterous laboratory reared soybean aphids were gently transferred to the underside of the uppermost unfolded-trifoliolates of V3 soybean plants using a blunt probe, and the mesh netting was closed.

For treatments receiving *B. communis* wasps in both experiments, we elected to use mummies (aphids parasitized by *B. communis* containing immature wasps ca. 6 d old). This ensured that the full egg-load of each wasp could be attained within the field, and maximized mating success. Leaves bearing mummies were excised from laboratory colonies, and attached to plants within the field using a paperclip.

Field Release Trials.To characterize the capacity of *B. communis* to colonize soybean aphid-infested soybean fields, and suppress soybean aphid growth in Iowa, caged release studies were conducted at several sites from 2008 to 2010. Treatments were randomly assigned to plots arranged in a randomized complete block design with four replicates (Fig. 2). The treatment design consisted of three levels that varied depending on whether the plots received mummies, and an exclusion cage. More specifically, our treatments were 1) un-caged control: open field plot, infested with 10 aphids per plant, referred to as the ‘U’ treatment; 2) caged control: caged plot, infested with 10 aphids per plant, referred to as the ‘A’ treatment; and 3) caged mummies: caged plot, infested with 10 aphids per plant and 20

mummies per cage, referred to as the ‘M’ treatment. Approximately 20 mummies were added to each M treatment approximately two weeks after plants were infested with aphids.

Comparisons of the M and A treatments allowed us to measure the effect of adding *B. communis* mummies in the short and long term on aphid population growth. Comparisons of the U treatment with the M treatment allowed us to assess whether abiotic and biotic factors of the environment were more important in the suppression of aphid populations than parasitism by *B. communis* alone.

To determine whether *B. communis* could effectively colonize adjacent patches of soybean aphids, M and A treatment cages were opened at the same time (approximately two weeks after mummies were added to the M treatment), allowing adult wasps to disperse throughout the field to previously established aphid populations of aphids that were not exposed to *B. communis* (U treatment plots).

Aphid Density Study. This experiment was designed to describe the relationship of initial host density on parasitism levels in a broad sense, and in a narrow sense as a description of the parasitoid’s functional response. To determine the effect of aphid density on *B. communis* parasitism levels within the field, we exposed *B. communis* to two different densities of aphids: a high density and a low density. A high density of aphids was achieved by adding 50 apterous laboratory reared aphids per plant to high treatments. A low density of aphids was achieved by infesting 20 apterous aphids per plant to low treatments. To promote even greater differences in aphid density, high treatments received aphids two weeks prior to the addition of aphids in low treatments. A subset of these treatments did not receive mummies, so that four treatments were contained within each block, with five replicates. Our

four specific treatments were 1) high aphid mummy: high aphid densities with mummies, referred to as the ‘Hm’ treatment; 2) low aphid mummy: low aphid densities with mummies, referred to as the ‘Lm’ treatment; 3) high aphid: high aphid densities without mummies, referred to as the ‘H’ treatment; and 4) low aphid: low aphid densities without mummies, referred to as the ‘L’ treatment. Each treatment was caged, and constructed as described in the cage construction section.

Comparisons of Hm and Lm treatments allowed us to test the effect of aphid density on the level of parasitism and persistence in the field. Comparisons of H and L treatments allowed us to test whether high or low aphid densities would be more attractive to *B. communis* searching for hosts once cages were opened (all cages were opened at the same time, approximately two weeks after adding mummies to Hm and Lm treatments).

Cages were assembled according to the methods described in the cage construction section. Each plant within each cage was counted bi-monthly throughout the 2009 and 2010 growing seasons.

Estimation of Aphid and Parasitoid Populations. *Field Release Trials*. The number of aphids and mummies were counted on each plant within each treatment plot bi-monthly throughout the growing season in 2008 through 2010. In order to provide a comparison of the density of aphids over the entire season, we used cumulative aphid-days (CAD). As described in Hanafi et al. (1989), CAD are estimated by summing the number of aphids accumulated between sampling dates:

$$\sum_{n-1}^{\infty}\left(\frac{x_{i-1}+x_i}{2}\right)\times t$$

where x is the average number of aphids counted on sample date i (per plant), x_{i-1} and is the average number of aphids counted on the previous sample date, and t is the number of days between sequential samples. By summing aphid days, a measure of aphid abundance which accounts for time is obtained.

Evaluation of each repetition of this experiment separately (for each site and year) utilized the number of aphids per plant, which were averaged for each plot to avoid pseudo-replication.

Aphid Density Study.The number of aphids and mummies were counted on each plant within each cage bi-monthly throughout the 2009 and 2010 growing seasons. The number of aphids and mummies were also counted on three consecutive soybean plants at ten random locations approximately 1.5 m away from the foci of each Hm and Lm cage. Although there were a considerable number of aphids counted at each of these locations after cages were opened, there were no mummies found.

Statistical Analysis. All analyses were conducted using SAS programs, version 9.2 (SAS Institute 2008) at a significance level of $P = 0.05$.

Field Release Trials. Data recorded and analyzed for this experiment include the number of aphids and mummies per plant, year, site, and sample date (represented as the number of days since infestation, denoted as day 0). To test the effect of *B. communis* releases on soybean aphid densities (expressed as CAD), we conducted a mixed model (PROC MIXED) analysis of variance (ANOVA) on treatment, the interaction of site and year, and block (nested within site and year). The interaction between site and year were

considered the 'environmental factor,' and the three-way interaction of site, year and treatment was treated as a random effect to evaluate the broad-sense inferences of the model.

Because the environmental factor of the analysis (site*year) was significant, we conducted a similar analysis on each year and site combination of the study separately, examining the effects of aphid density (measured as the number of aphids per plant). A general linear model (PROC GLM) ANOVA was conducted for each year and site separately by date (factors were treatment and block) to determine the effects of *B. communis* on soybean aphid populations. The number of mummies formed in F_2 and F_3 generations was analyzed using the same procedure. Aphid and mummy population means were separated across treatments for each site and sample date using Tukey's honestly significant difference test (HSD). Aphid and mummy populations were analyzed as the average number of individuals per plant, and were subsequently $\log_e(x + 1)$ transformed prior to analysis to meet assumptions of normality and constant variance; the raw data are presented in subsequent tables, and back-transformed data are presented in figures.

Aphid Density Study. To determine the effects of treatment, date, and site on aphid populations for the aphid density study, a mixed model analysis of variance was utilized (PROC MIXED). Treatment, date, site, and the interaction of treatment with date, and site with treatment were treated as fixed effects, with the block by treatment interaction nested within site and date treated as random effects. The same model was employed to determine these effects on F_2, F_3, and F_4 mummy populations.

To determine the effect of treatment on the density of mummies at each sample date for each site and year separately, we conducted a mixed model ANOVA using the factors

treatment, block, and date. Treatment, block, and the treatment by date interaction were treated as fixed effects, while the interaction of treatment and block nested within date were treated as a random effect. Least-square means tests were computed on treatment sliced across date when the date by treatment interaction was significant.

In order to ensure data conformed to the assumptions of ANOVA and regression, residuals were examined for homoscedasticity, and independence using plots of residuals by predicted values. Normality was tested using the Shapiro-Wilk test (Royston 1995).

Results

Field Release Trials. Aphid densities were significantly different across treatments for all data combined from 2008 to 2010 ($F = 26.89$; df = 2, 18; $P < 0.001$), which lacked a significant block effect ($F = 0.71$; df = 30, 60; $P = 0.850$). Aphid densities were not significantly different between caged treatments that received mummies, and caged treatments that did not receive mummies (M vs. A: $t = 0.12$; df = 18; $P = 0.903$). Aphid densities were significantly different in caged versus un-caged treatments (A and M vs. U: $t = 7.33$; df = 18; $P < 0.001$). There was not a significant difference in the number of aphids across years for most sites (N: $F = 2.09$; df = 1, 18; $P = 0.1656$; NW: $F = 2.44$; df = 1, 18; $P = 0.136$; SE: $F = 1.39$; df = 2, 18; $P = 0.276$), with exception of the Southern site ($F = 7.64$; df = 2, 18; $P = 0.004$). There was a significant difference in the number of aphids across sites in 2008 ($F = 13.16$; df = 3, 18; $P < 0.001$) and 2010 ($F = 11.85$; df = 2, 18; $P < 0.001$), but not in 2009 ($F = 1.81$; df = 2, 18; $P = 0.192$). After cages were opened to allow *B. communis* to disperse throughout the field, 37.5% of previously parasitoid-free cages (treatment plots A and U) contained *B. communis* mummies (excluding one experiment). The study site

excluded from this calculation (Northern site; Hancock County) experienced torrential weather; coincidentally, all of the mummy infestation cages (M) were torn open, while none of the non-infestation cages (A) were opened. To this end, only this location exhibited 100% host patch residence.

Parasitoid densities were significantly different across treatments for all data combined from all years and sites ($F = 34.25$; df = 2, 16; $P < 0.001$). Significant differences were only reflected in the difference between cages that were inoculated with *B. communis*, and those that weren't (M vs. A and U: $t = 8.28$; df = 16; $P < 0.001$); thus, no significant differences existed between caged and un-caged control which were not inoculated with mummies at the start of the experiment (A vs. U: $t = 0.03$; df = 16; $P = 0.974$). Because the environmental variable (year by site interaction) was found to be significant ($F = 34.25$; df = 8, 16; $P < 0.001$), we examined the simple effects separately. There were no significant site effects for mummy densities in 2008 ($F = 1.91$; df = 2, 16; $P = 0.170$) and 2010 ($F = 1.41$; df = 2, 16; $P = 0.273$), but mummy density was significantly different across sites in 2009 ($F = 6.79$; df = 2, 16; $P = 0.007$). In contrast, there were no significant differences in the number of mummies produced across years for any of the sites (NW: $F = 1.69$; df = 1, 16; $P = 0.212$; N: not enough degrees of freedom to determine; S: $F = 0.82$; df = 2, 16; $P = 0.459$; SE: $F = 0.38$; df = 2, 16; $P = 0.693$).

The interaction effect of year by site was significant for all data combined ($F = 3.03$; df = 8, 16; $P = 0.028$), therefore the effect of treatment on aphid and mummy populations were analyzed by date for each year and site separately. Mean treatment comparisons for the Northern site reveal that in 2008, there was no significant difference in the number of aphids in M versus A cages (Appendix A1; Fig. 4a). In 2009, M treatment cages sustained

marginally significant lower aphid populations than A cages (Appendix A2; Fig. 4b) following the addition of mummies on sample date 2; however, after cages were opened (sample dates 3-4), aphid populations were not significantly different for caged treatments M and A (Appendix A2; Fig. 4b). Consistent with statistical results of the entire dataset, treatment did not significantly affect the abundance of mummies, except when comparing treatments which were inoculated with *B. communis*, and those that were not (Appendix A1, A2; Fig. 4c,d).

In Northwestern Iowa, aphid populations were extremely variable in 2008, ultimately leading to aphid populations that were nearly as high in un-caged controls as in caged controls (Fig. 5a). Mummy addition on 8 July 2010 altered aphid populations from significantly lower in M versus A treatment cages on 23 July, but on 5 August, aphid populations within M treatment cages were not significantly different than A treatment cages (Appendix A3; Fig. 5b). In the sample dates that followed for both 2008 and 2010, aphid populations within M treatments became significantly higher than aphid populations within A treatments.

In Southern Iowa, mummy addition on 18 July 2008, 9 July 2009, and 21 July 2010 did not result in significantly lower aphid populations within M versus A treatments (Appendix A1, A2, A3; Fig. 6a, 7a, and 8a respectively). In fact, aphid populations were marginally higher in M treatments following mummy addition in 2008, and 2010. Mummy populations remained relatively high within release plots, and extremely low in non-release plots A and U (Fig. 6b, 7b, and 8b).

In Southeastern Iowa, mummy addition on 16 July 2008 resulted in populations within M and A that were not statistically different (Appendix A1; Fig. 9a). Mummy addition

on 26 June 2009 resulted in significantly lower aphid populations within M as compared to A treatments (Appendix A2; Fig. 10a), and mummy addition on 21 July 2010 resulted in significantly higher aphid populations within M as compared to A cages in 2010 (Appendix 3A3; Fig. 11a). Mummy populations tended to dominate within A treatment cages instead of M treatment cages in 2009 and 2010 (Fig. 10b and 11b respectively). This pattern was also observed at the Southern site in 2010 (Fig. 8b).

Aphid Density Study. Aphid density was significantly affected by treatment (F = 28.31; df = 3, 176; $P < 0.001$), date (F = 25.75; df = 3, 176; $P < 0.001$), site (F = 16.04; df = 2, 176; $P < 0.001$), the date by treatment interaction (F = 13.78; df = 9, 176; $P < 0.001$), and the site by treatment interaction (F = 2.59; df = 6, 176, P = 0.020). Mummy density was significantly affected by treatment (F = 86.20; df = 3, 176; $P < 0.001$), site (F = 14.55; df = 2, 176; $P < 0.001$), the date by treatment interaction (F = 3.15; df = 9, 176; P = 0.002), and the site by treatment interaction (F = 8.75; df = 6, 176; $P < 0.001$). However, mummy density was not significantly affected by date (F = 1.97; df = 3, 176; P = 0.120).

The initial density of aphids within Hm and Lm treatment cages upon release of *B. communis* was significantly different for the Central site in 2009 (t = 13.15; df = 56; $P < 0.001$) and 2010 (t = 13.93; df = 60; $P < 0.0001$), the Northwestern site in 2009 (t = 4.00; df = 42; $P < 0.001$), and the Northern site in 2010 (t = 3.67; df = 44; $P < 0.001$). Significantly more mummies were produced within cages containing lower densities of aphids at both sites in 2009 (Appendix A4; Fig. 12,13; PROC MIXED, $\alpha = 0.05$). However, when *B. communis* was allowed to choose between high and low densities of aphids (i.e., H and L cages) in its third and fourth generation, mummy densities were not significantly affected by high nor low

aphid density treatments at any site or in any year (PROC MIXED, $P < 0.05$) (Appendix A4, A5). Interestingly, in 2010, torrential weather at the Northern site consequently ripped open cages prematurely; thus introducing some experimental error (Fig. 13). However, this accidental occurrence provides an interesting perspective on the biology of this parasitoid. Each of the H treatment blocks that were unintentionally opened by the storm were colonized by *B. communis.*

Discussion

If and when imported biological control agents do not provide or contribute to significant suppression of target pest populations, multiple, or alternative candidates must be considered for release against the target pest population. Often times, the parasitoid is not well described in its native range, and foreign explorations may not provide adequate time to determine whether the parasitism is an incidental association (parasitoid incidence on the target pest resulting from the overflow of parasitoids from their preferred host), or a strong association. The only assured method to test the efficacy of an imported biological control agent is to conduct preliminary field releases at a number of sites with varied environmental conditions (Bartlett and van den Bosch 1964). Establishment of an introduced parasitoid may be limited by the following environmental factors: (1) inability to survive the local climate; (2) the target host is not its preferred host; (3) poor synchronization of the phenology of the target within the new range; and (4) and the absence of an obligatory alternate or overwintering host. In addition, biotic factors such as intraguild predation (predation with conspecific natural enemies also feeding on soybean aphid), and experimental factors such as

release technique may also limit the establishment of introduced parasitoid species (Van Driesche et al. 2008).

The criteria for determining the success of classical biological control releases is not particularly rigid; therefore, reports of successful pest suppression by parasitoids may be exaggerated due to misconceptions of the scientific and agricultural community of their effect on insect pests. Bedding et al. (1978) found that historically, studies have overestimated the extent to which parasitoids exert top-down control on insect populations, in contrast to 'natural control' resulting from multiple links in complex food webs. He calculated the degree to which a host population may be reduced in abundance by an introduced parasitoid, using the equation, $q = N^*/K$, where N is the average abundance of the host in the presence of the parasitoid (post-introduction), and K is the average abundance of the host prior to introduction of the parasitoid. From this study, he calculated the q-values for six different field parasitoid-host systems (cases of successful biological control), and found that host populations were depressed approximately one hundredth of their former abundance. This may explain why classical biological control programs (as in the case of *B. communis*) often 'fail' to meet the standards of successful control. Identifying a parasitoid species that possess a reproductive rate and high searching efficiency capable of suppressing soybean aphid populations below the economic threshold in the field may be an enormous task. Regulations governing the importation and release of biological control agents may limit the potential for importing the most prolific biological control agent possible.

Despite relatively promising results from pre-release tests of the imported parasitoid wasp *B. communis* against the invasive soybean aphid in the laboratory, field releases suggest that control of the soybean aphid by *B. communis* is insufficient within the context of

biological control. The failure of *B. communis* to adequately disperse and parasitize soybean aphids within host patches despite the release site or year releases were conducted, suggests the occurrence of an apparent preoviposition avoidance of wasps by aphids, or deterrence of *B. communis* from aphid host patches. Preoviposition avoidance may be the result of host-parasitoid population dynamics such as host switching behavior (i.e., *B. communis* may require an obligate alternate or overwintering host), or defensive behavior exhibited by the soybean aphid.

Aphis glycines may be an inferior host of *B. communis* in its native range of China. Venette and Ragsdale (2004) analyzed climatic similarity of US regions to the origins of aphid species intercepted by USDA, APHIS, PPQ (The US Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine), and found that the soybean aphid most likely originated from Japan, in contrast to the strain of *B. communis* used in this study, which was collected from northeast China (Desneux et al. 2009c). *Binodoxys communis* was found to be an 'olfactory generalist' (cannot distinguish between target- and non-target host-plant complexes (HPCs) (Wyckhuys and Heimpel 2007), increasing the likelihood of death from random patch searching if and when searching a preferred or overwintering host, which is likely only found in China and/or Japan.

Host-plant genetics is another important factor involved in the relationship between plant, pest, and parasitoid. Michel et al. (2010) compared the genetic variation of five laboratory populations of soybean aphid in four midwestern states, and found that laboratory populations had lost more than 50% of their genotypic diversity in a matter of five months. A loss of genetic diversity may have reduced the preference of *B. communis* for laboratory reared soybean aphid biotypes within the confines of this study.

As the number of aphids increases per patch, so does the likelihood of their mortality, due to factors involved in plant quality, fungal epizootics, and abiotic factors. By laying a higher proportion of eggs within patches containing higher densities of hosts (acting in a density-dependent manner), parasitoids are better able to overcome higher host mortality normally encountered in patches containing large host densities (Stiling 1988). When presented with aphid densities at or below 300 per plant, *B. communis* acted in a directly density-dependent manner. However, the effect of aphid densities on *B. communis* survival and parasitism appeared to be inversely density-dependent when examining the behavior of wasps in host densities not normally encountered in nature above 300 aphids per plant (Fig. 14). It is likely that *B. communis* was deterred from extremely dense host patches in order to avoid intraguild predation (Chacón et al. 2008, 2010), or that the adult wasps or developing larvae were negatively affected by increased aphid defenses due to host-aggregation factors. Host aggregation may function to amplify the detrimental effects of defense mechanisms in response natural enemies such as alarm pheromones, or immune responses at higher clonal densities. Butler and O'Neil (2006) found that cornicular exudates produced by soybean aphids can significantly reduce the survival of *O. insidiosus* within the lab, suggesting that this exudate might contain an alarm pheromone. Verheggen (2008) identified the aggregation pheromone of soybean aphids as (E)-β-Farnesene, and Wu et al. (2010) found that higher densities of aphids increased the risk of aphids smearing the defensive exudate on the mouthparts of parasitoids. At higher aphid densities, emergence of adult wasps has been found to decrease. Insects in crowded conditions have been shown to allocate more resources to their immune function due to a greater risk of parasitism in dense patches (density-dependent prophylaxis, DDP) (Wilson and Reeson 1998). Despite this fact, we found that *B.*

communis acted in a directly density-dependent manner when exposed to varying densities of aphids below or slightly above the economic threshold for the soybean aphid (Ragsdale et al. 2007), suggesting that if *B. communis* were able to colonize soybean fields infested with soybean aphids early enough in the season, it would act in a manner to adequately reduce the population to a manageable level before the generalist, more voracious natural enemies arrive.

In summary, un-caged treatments maintained the lowest levels of soybean aphid populations. This work indicates that the best approach to take is an integrated one, whereby natural control (conservational biological control) is combined with classical biological control. Du et al. (1994) found that odors of "other plants," (i.e., not soybean) interfered with the attraction of soybean aphid to soybean. Partial early season suppression of the soybean aphid via *B. communis* may be possible under the concept of 'integrated biological control' (Wratten 1992). In this way, if an alternate host is needed for the permanence of *B. communis* within the agroecosystem, the parasitoid may be restricted to the confines of the non-crop habitat when soybean aphids are scarce, overwintering success may be improved, as well as its fecundity through the utilization of floral subsidies in times of extremely high soybean aphid densities. If an exotic alternate host is required for overwintering success of *B. communis,* partial control of the soybean aphid may be possible via augmentative releases earlier in the season, when aphid densities are still very low.

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Figure Legends

Fig. 1. Field release sites and host density locations throughout Iowa. Sites are referred to as the following: Northwestern (NW), Northern (N), Central (C), Southeastern (SE), and Southern (S). Symbols indicate year of farm utilization (squares, 2008; circles, 2009; triangles, 2010); shading (dark shading indicates field releases to determine *B. communis* spread) indicates field study conducted.

Fig. 2. Field release trials plot design. Ten aphids were added per plant in all treatments plots for the aphid release study, and U-cages are open field plots. Twenty mummies were added to each M treatment plot in 2008, and 50 mummies were added to each M treatment plot in 2009 and 2010.

Fig. 3. Aphid density field plot design. Fifty aphids were added to each plant in Hm and H (Hm: high aphid density, mummy inoculation cage; H: high aphid density cage) plots, and 20 aphids were added to each plant in Lm and L (Lm: low aphid density, mummy inoculation cage; L: low aphid density cage) plots within each block. Shaded circles represent paired cages with high and low aphid densities which received mummies; un-shaded circles represent paired cages with high and low aphid densities which did not receive mummies.

Fig. 4. Mean aphids in 2008 (A), 2009 (B), and mean mummies in 2008 (C), and 2009 (D) across treatments for each sample date at the Northern release site. Treatments: A,

aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, α = 0.05). Arrows indicate the date that mummies were added. Values are $\log_e(x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig. 5. Mean aphids (A) and mummies (B) across treatments for each sample date at the Northwestern release site. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, α = 0.05). Arrows indicate the date that mummies were added. Values are $\log_e(x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig. 6. Mean aphids (A) and mummies (B) across treatments for each sample date at the Southern release site for 2008. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, α = 0.05). Arrows indicate the

date that mummies were added. Values are $\log_e (x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig. 7. Mean aphids (A) and mummies (B) across treatments for each sample date at the Southern release site for 2009. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, $\alpha = 0.05$). Arrows indicate the date that mummies were added. Values are $\log_e (x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig. 8. Mean aphids (A) and mummies (B) across treatments for each sample date at the Southern release site for 2010. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different (Tukey's HSD, $\alpha = 0.05$) for $\log_e (x+1)$ aphid abundance per treatment. Arrows indicate the date that mummies were added. Error bars are back-transformed standard errors of the mean.

Fig. 9. Mean aphids (A) and mummies (B) across treatments for each sample date at the Southeastern release site for 2008. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U,

aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, $\alpha = 0.05$). Arrows indicate the date that mummies were added. Values are $\log_e(x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig.10. Mean aphids (A) and mummies (B) across treatments for each sample date at the Southeastern release site for 2009. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, $\alpha = 0.05$). Arrows indicate the date that mummies were added. Values are $\log_e(x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig. 11. Mean aphids (A) and mummies (B) across treatments for each sample date at the Southeastern release site for 2010. Treatments: A, aphids infested within exclusion cages; M, aphids released within exclusion cages, as well as *B. communis* wasps; U, aphids infested within open field plots. Letters that are the same are not significantly different in aphid density, and asterisks indicate significantly higher mummy densities per plant across treatments (Tukey's HSD, $\alpha = 0.05$). Arrows indicate the date that mummies were added. Values are $\log_e(x+1)$ back-transformed. Error bars are standard errors of the mean.

Fig. 12. 2009 *Binodoxys communis* host density study 2009 results. Numbers of aphids (bars, primary y-axis) and mummies (lines, secondary y-axis) plus standard errors of the mean. Hm, cage infested with high densities of *A. glycines*, and inoculated with *B. communis*; Lm, cage infested with low densities of *A. glycines*, and inoculated with *B. communis* * indicates a significant difference in $\log_e(x+1)$ mummy density between Hm and Lm (PROC MIXED, $\alpha = 0.05$). Arrows indicate the date that mummies were added.

Fig. 13. 2010 *Binodoxys communis* host density study 2010 results. Numbers of aphids (bars, primary y-axis) and mummies (lines, secondary y-axis) plus standard errors of the mean. Hm, cage infested with high densities of *A. glycines*, and inoculated with *B. communis*; Lm, cage infested with low densities of *A. glycines*, and inoculated with *B. communis* * indicates a significant difference in $\log_e(x+1)$ mummy density between Hm and Lm (PROC MIXED, $\alpha = 0.05$). Arrows indicate the date that mummies were added.

Figure 1.

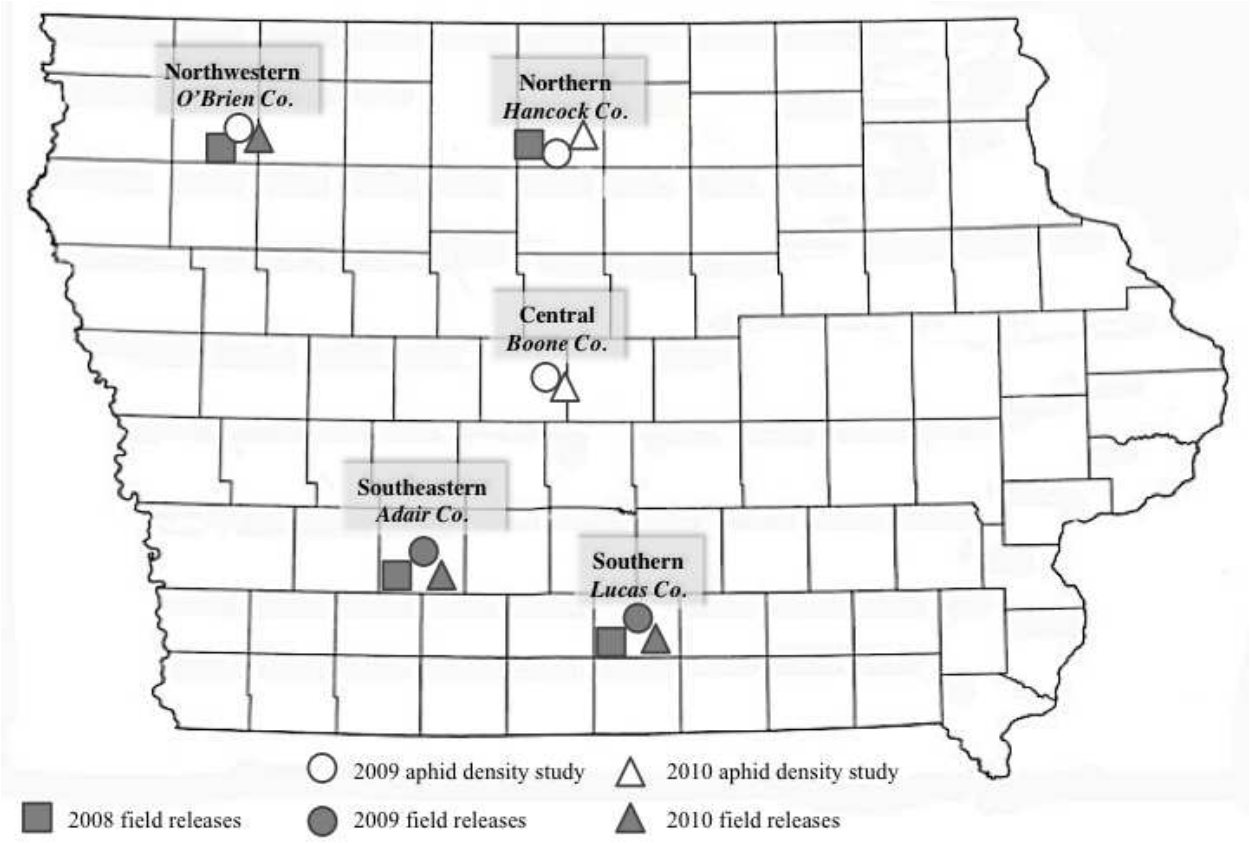

Northwestern
O'Brien Co.
Northern
Hancock Co.
Central
Boone Co.
Southeastern
Adair Co.
Southern
Lucas Co.
2009 aphid density study
2010 aphid density study
2008 field releases
2009 field releases
2010 field releases

Figure 2.

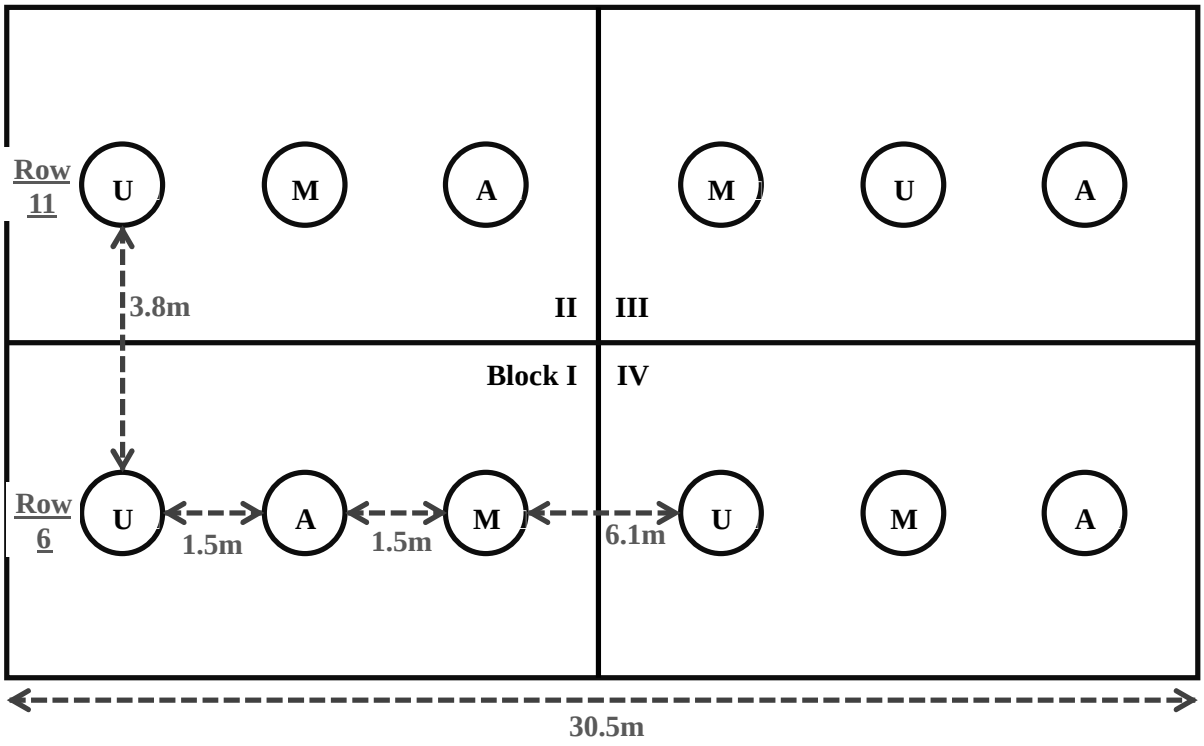

Row 11
U
M
A
M
U
A
3.8m
II
III
Block I
IV
Row 6
U
A
M
U
M
A
1.5m
1.5m
6.1m
30.5m

Figure 3.

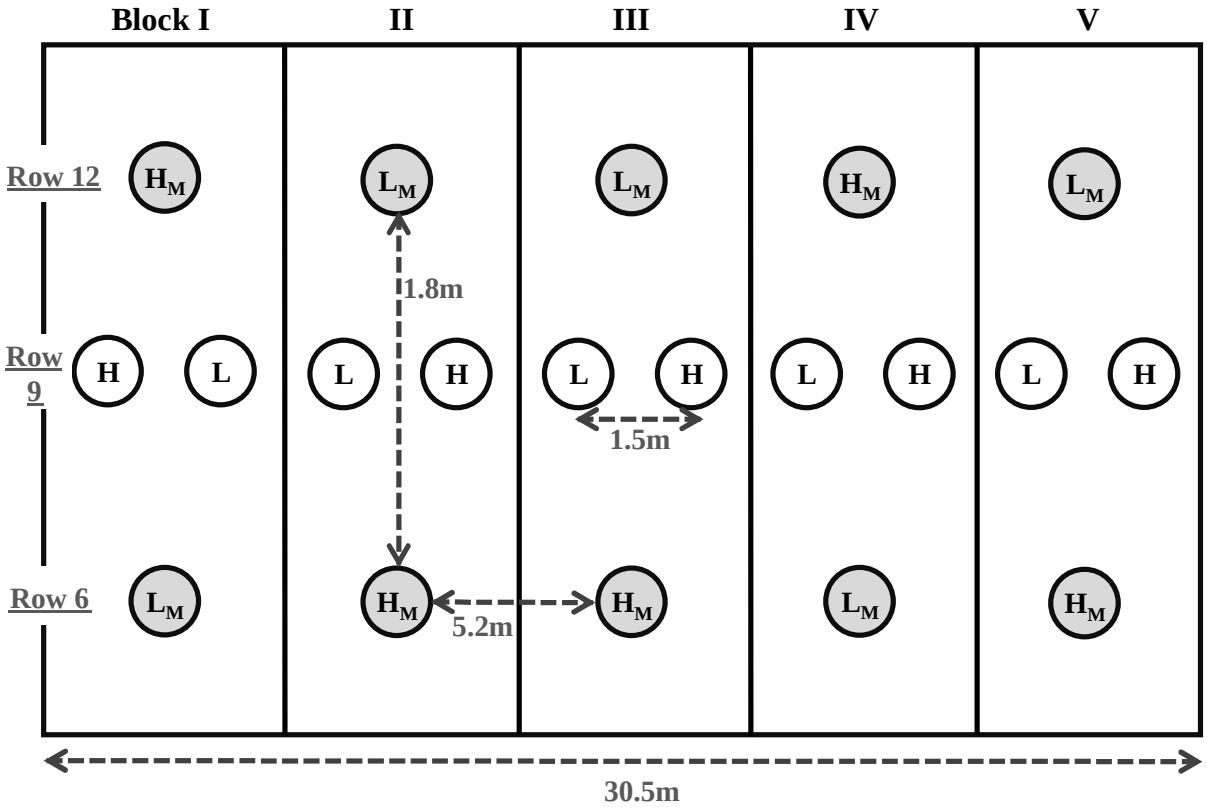


Figure 4.

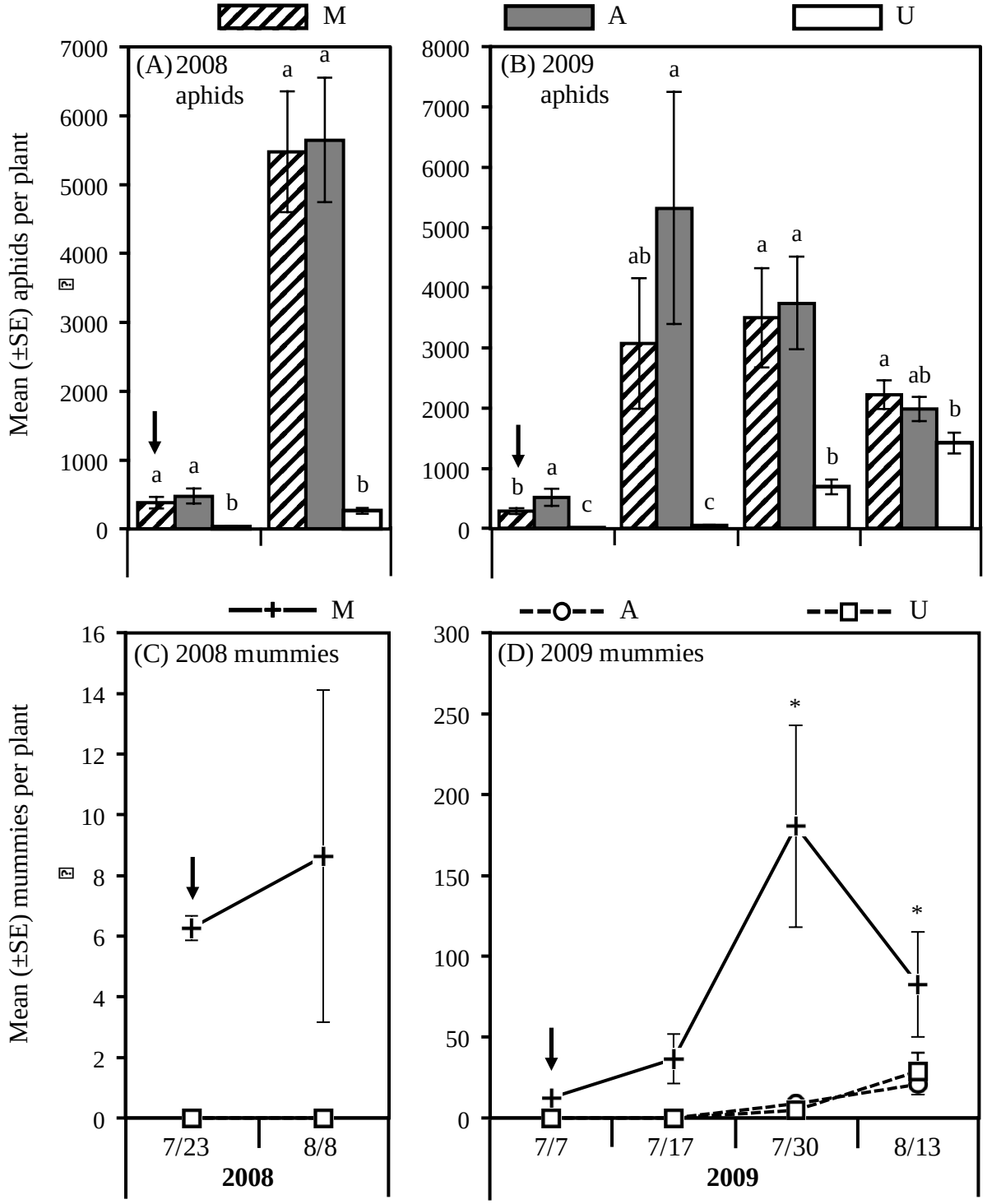

M
A
U
(A) 2008 aphids
(B) 2009 aphids
Mean (±SE) aphids per plant
(C) 2008 mummies
(D) 2009 mummies
Mean (±SE) mummies per plant
7/23
8/8
2008
7/7
7/17
7/30
8/13
2009

Figure 5

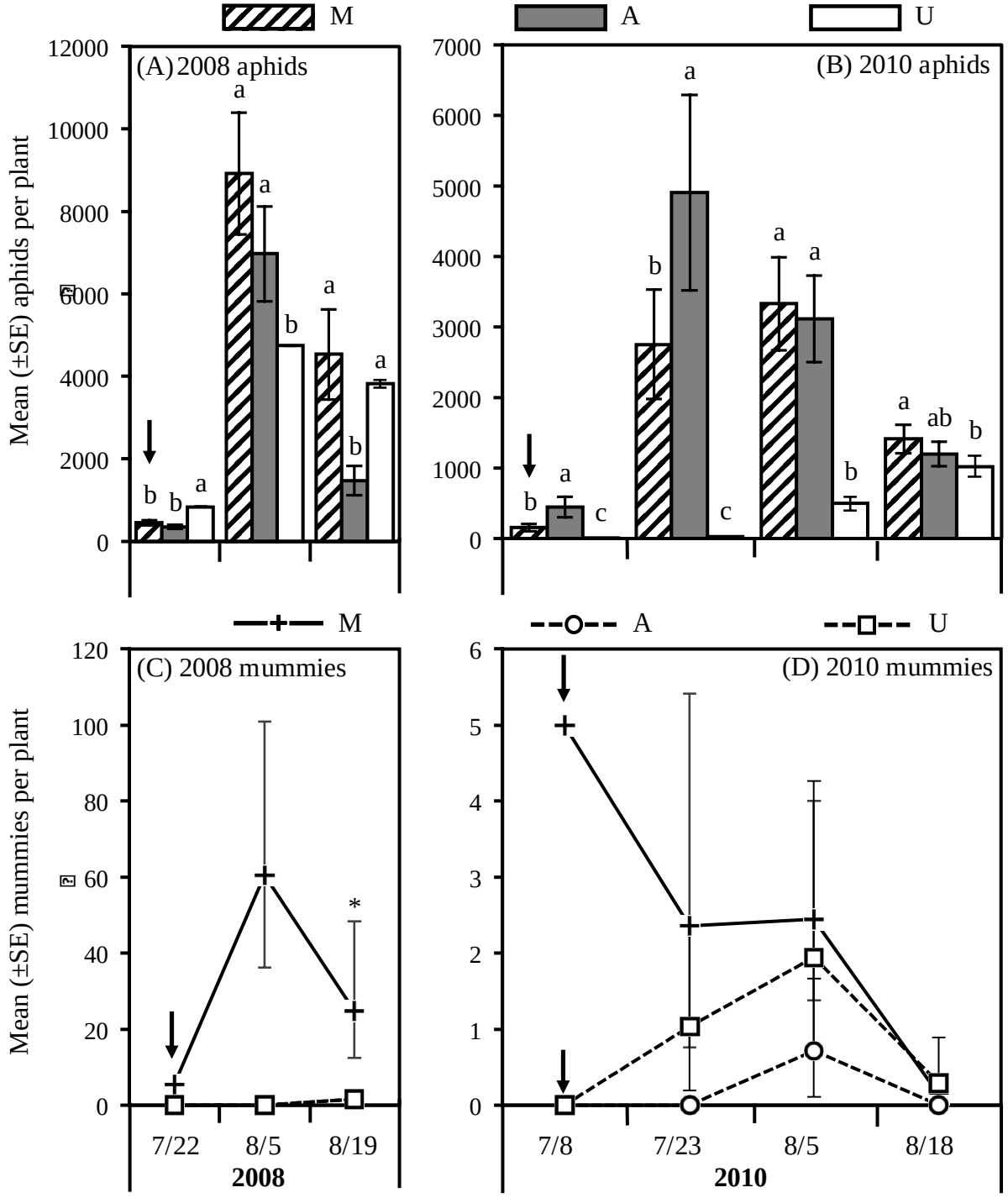

M
A
U
(A) 2008 aphids
(B) 2010 aphids
Mean (±SE) aphids per plant
12000
10000
8000
6000
4000
2000
0
7000
6000
5000
4000
3000
2000
1000
0
b b a
a a b a b a
b a c
b a c
a a b
a ab b
M
A
U
(C) 2008 mummies
(D) 2010 mummies
Mean (±SE) mummies per plant
120
100
80
60
40
20
0
6
5
4
3
2
1
0
*
7/22
8/5
8/19
2008
7/8
7/23
8/5
8/18
2010

Figure 6.

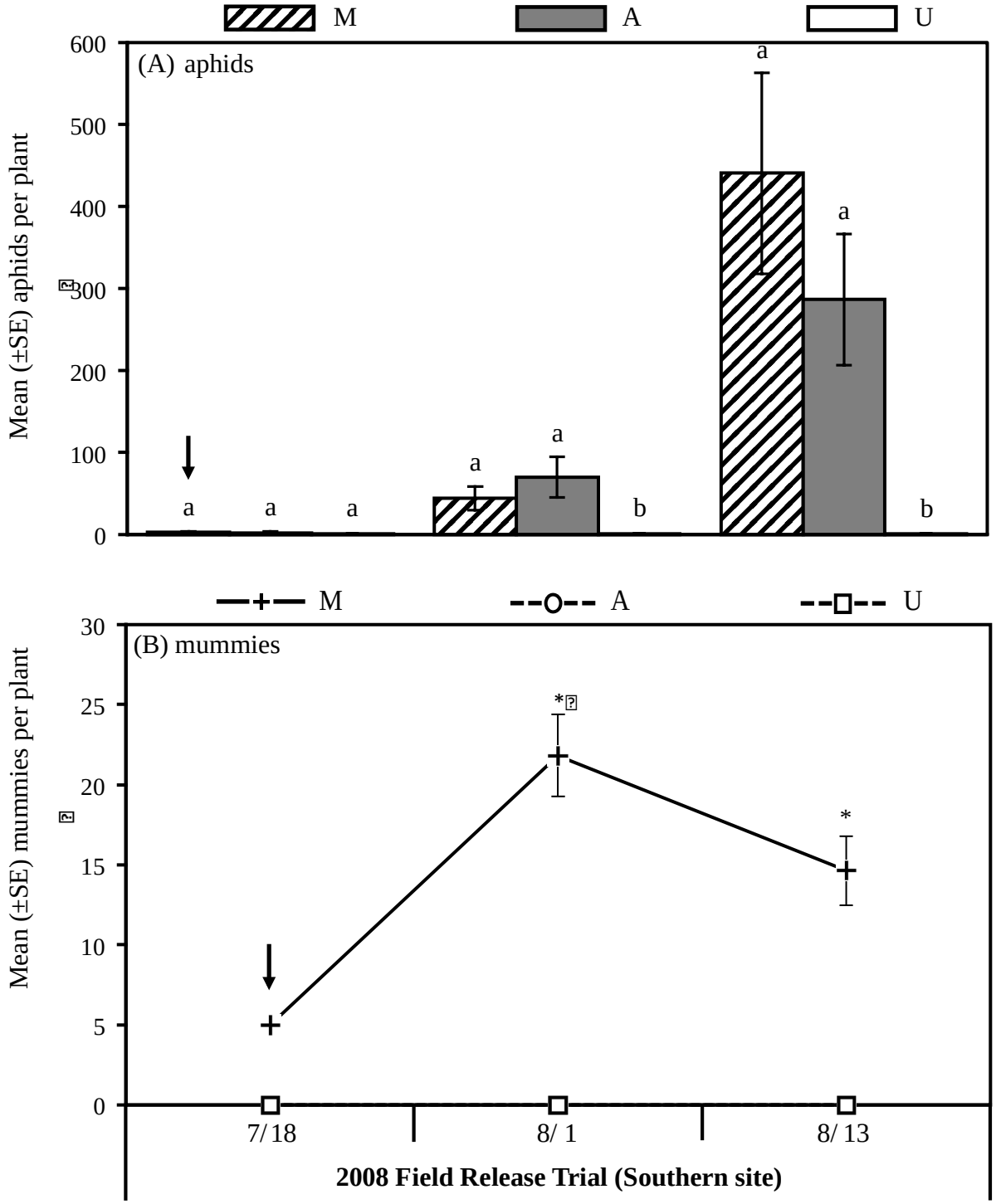

M
A
U
(A) aphids
Mean (±SE) aphids per plant
600
500
400
300
200
100
0
a
a
a
a
a
b
a
a
b
M
A
U
(B) mummies
Mean (±SE) mummies per plant
30
25
20
15
10
5
0
*
*
7/18
8/1
8/13
2008 Field Release Trial (Southern site)

Figure 7.

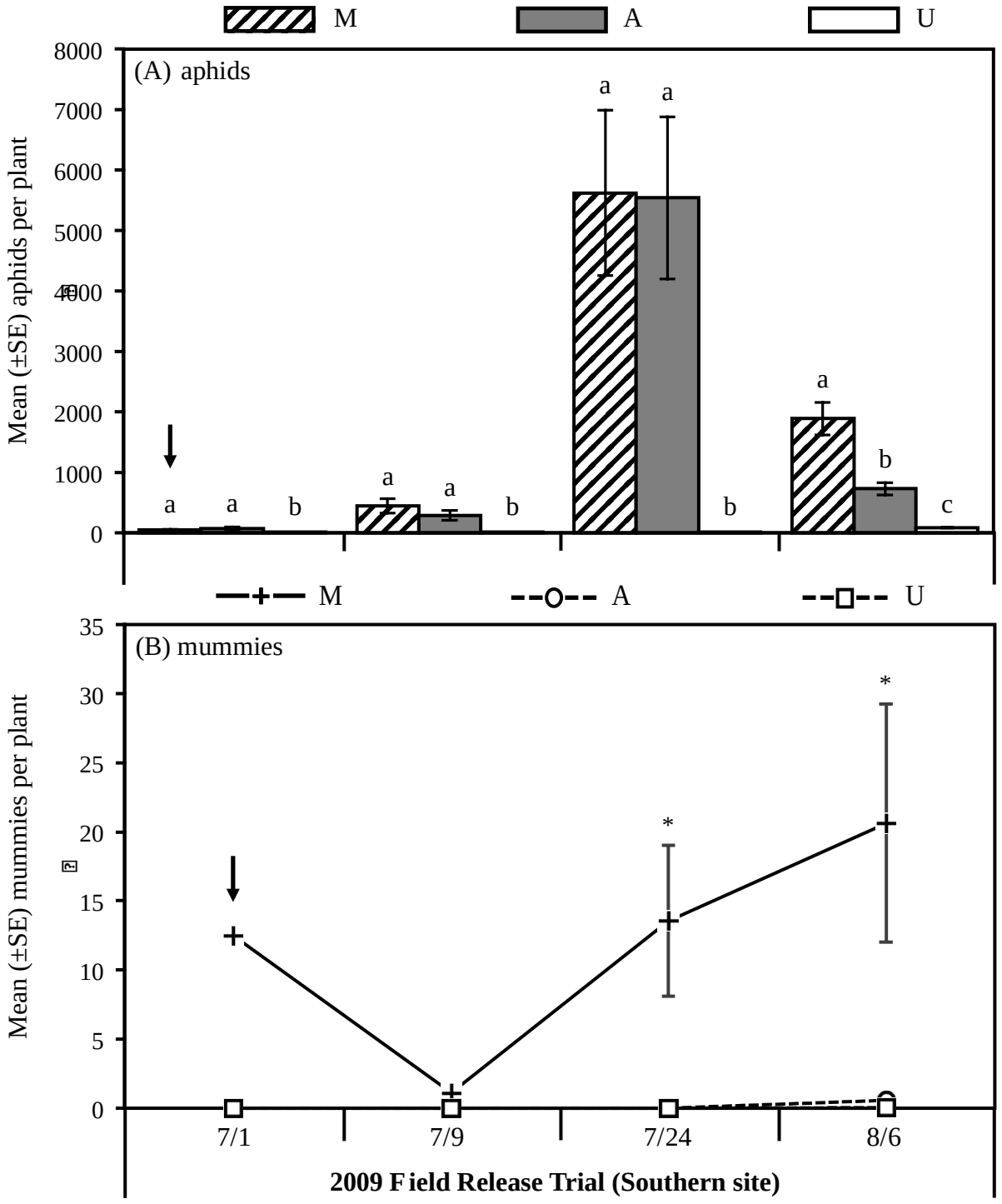

M
A
U
(A) aphids
Mean (±SE) aphids per plant
8000
7000
6000
5000
4000
3000
2000
1000
0
a
a
b
a
a
b
a
a
b
a
b
c
M
A
U
(B) mummies
Mean (±SE) mummies per plant
35
30
25
20
15
10
5
0
*
*
7/1
7/9
7/24
8/6
2009 Field Release Trial (Southern site)

Figure 8.

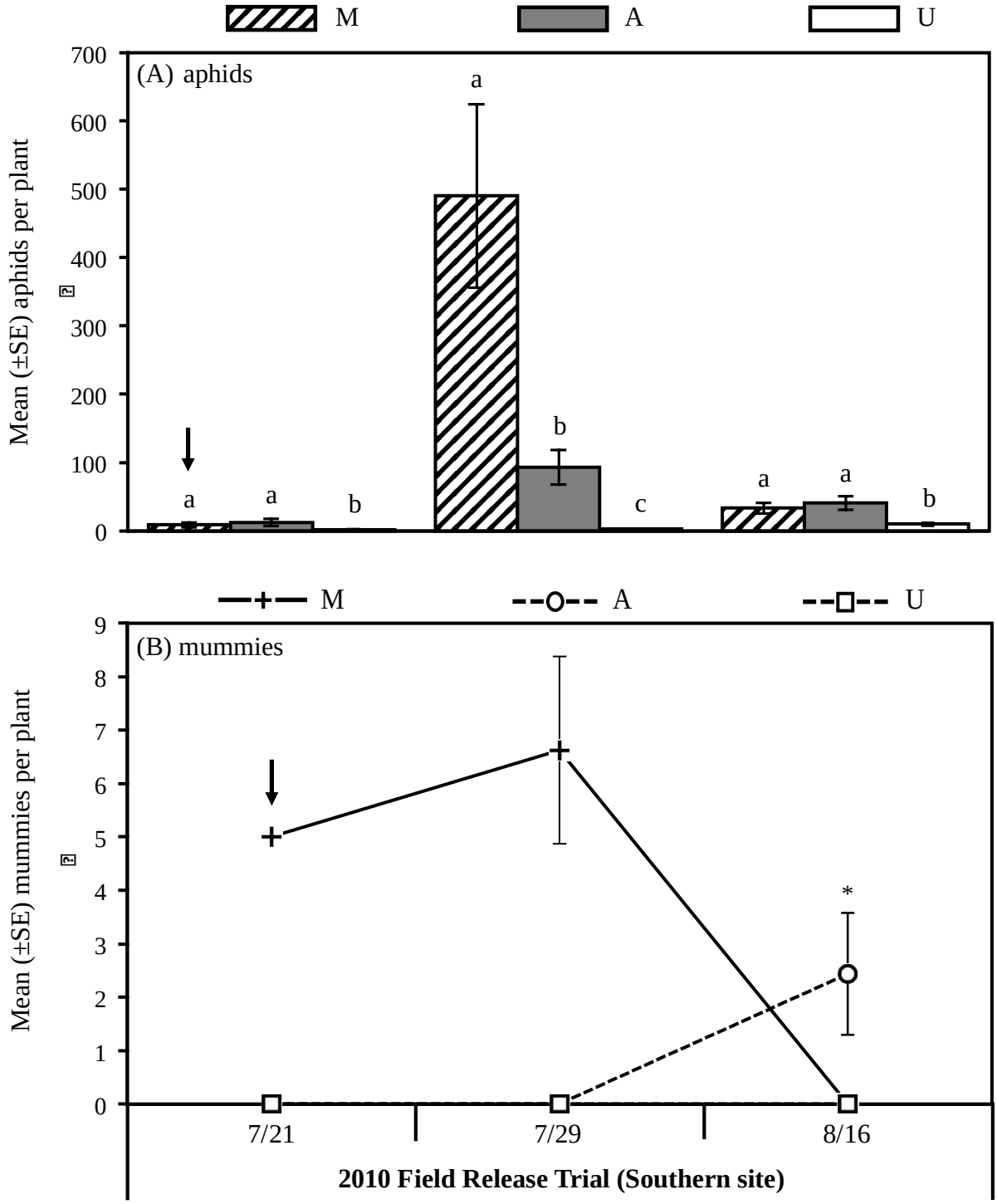

M
A
U
(A) aphids
Mean (±SE) aphids per plant
700
600
500
400
300
200
100
0
a
a
b
a
b
c
a
a
b
(B) mummies
Mean (±SE) mummies per plant
9
8
7
6
5
4
3
2
1
0
*
7/21
7/29
8/16
2010 Field Release Trial (Southern site)

Figure 9.

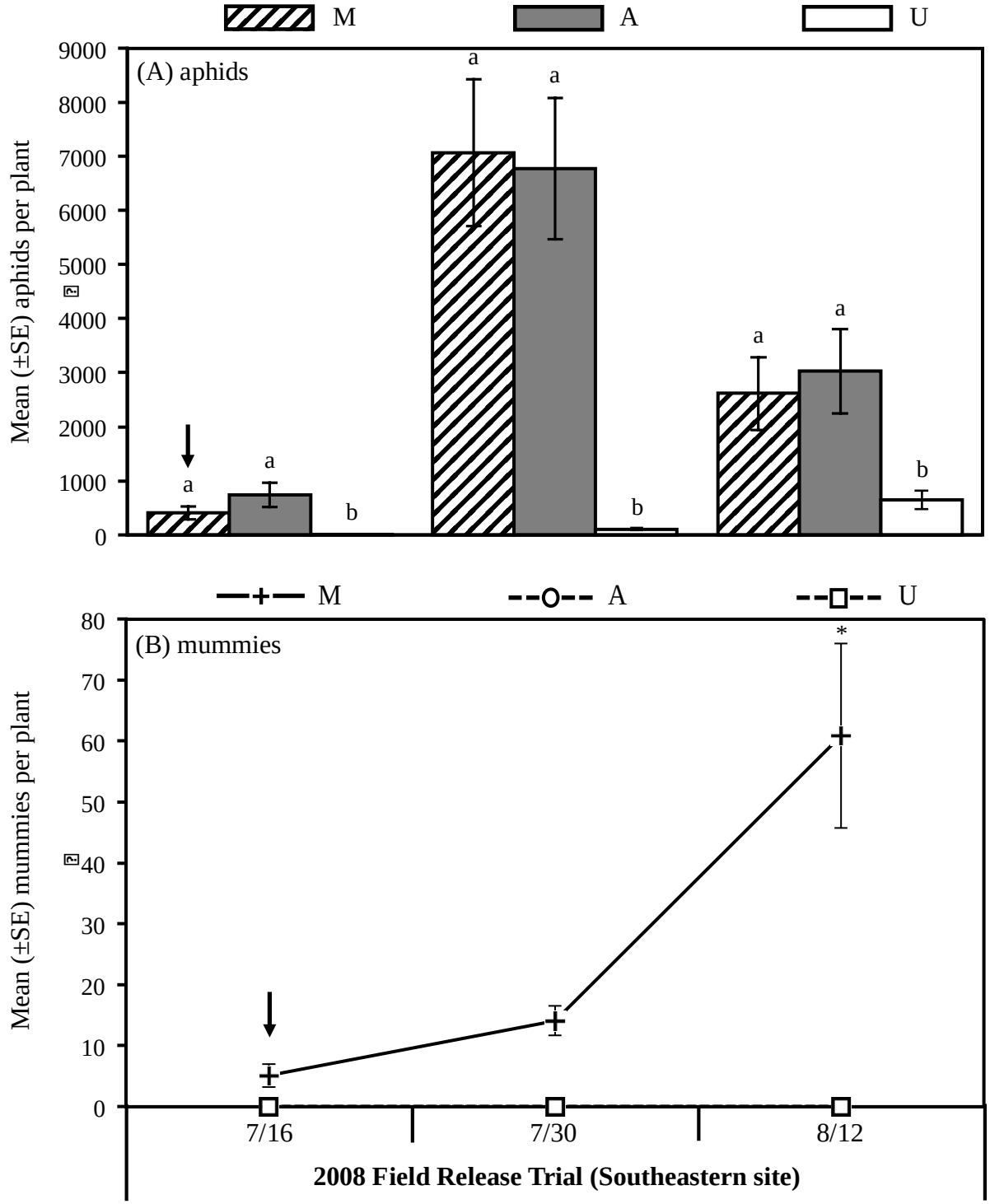

M
A
U
(A) aphids
Mean (±SE) aphids per plant
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
a
a
b
a
a
b
a
a
b
M
A
U
(B) mummies
Mean (±SE) mummies per plant
80
70
60
50
40
30
20
10
0
*
7/16
7/30
8/12
2008 Field Release Trial (Southeastern site)

Figure 10.

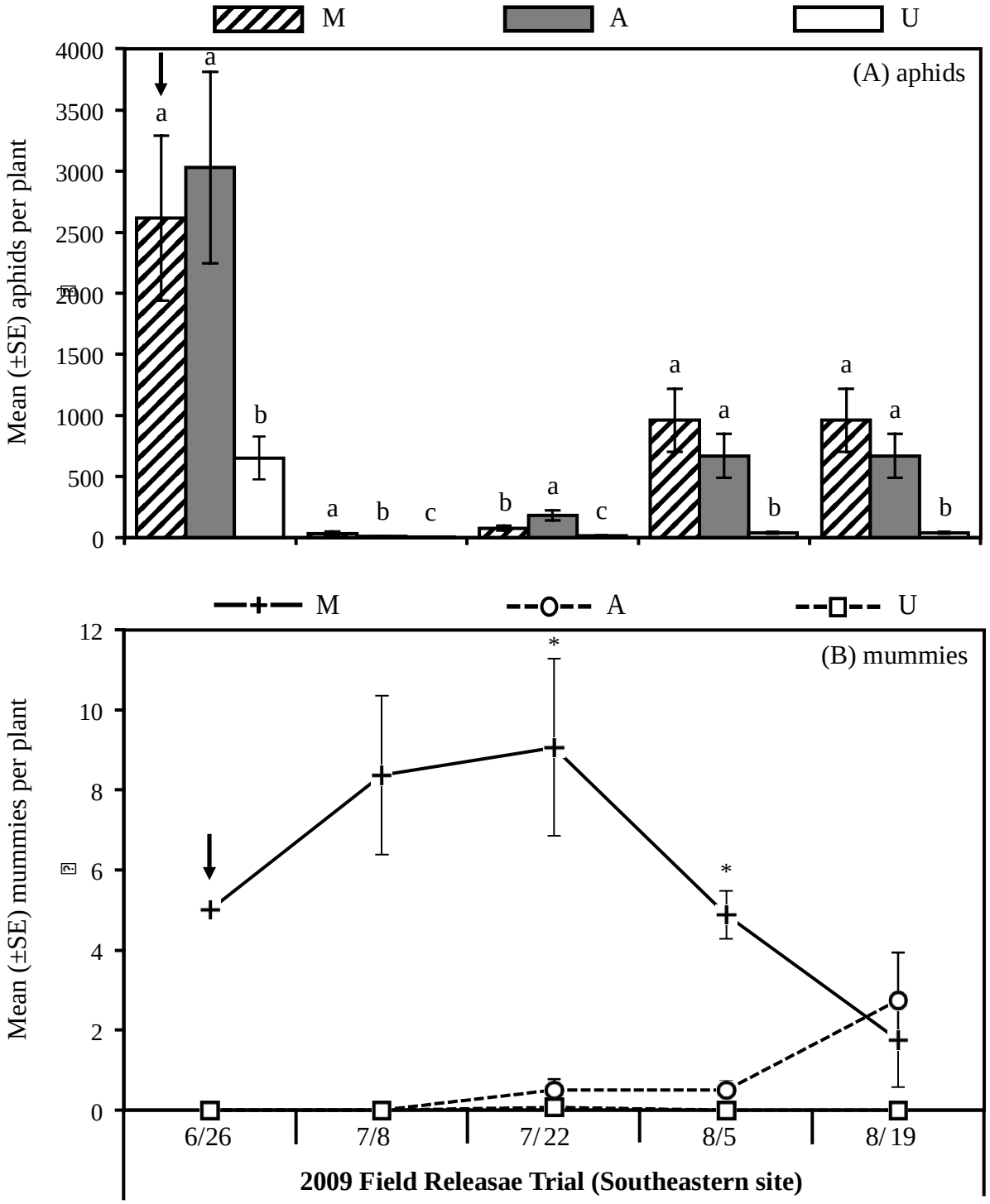

M
A
U
(A) aphids
Mean (±SE) aphids per plant
4000
3500
3000
2500
2000
1500
1000
500
0
a
a
b
a
b
c
b
a
c
a
a
b
a
a
b
(B) mummies
Mean (±SE) mummies per plant
12
10
8
6
4
2
0
*
*
6/26
7/8
7/22
8/5
8/19
2009 Field Releasae Trial (Southeastern site)

Figure 11.

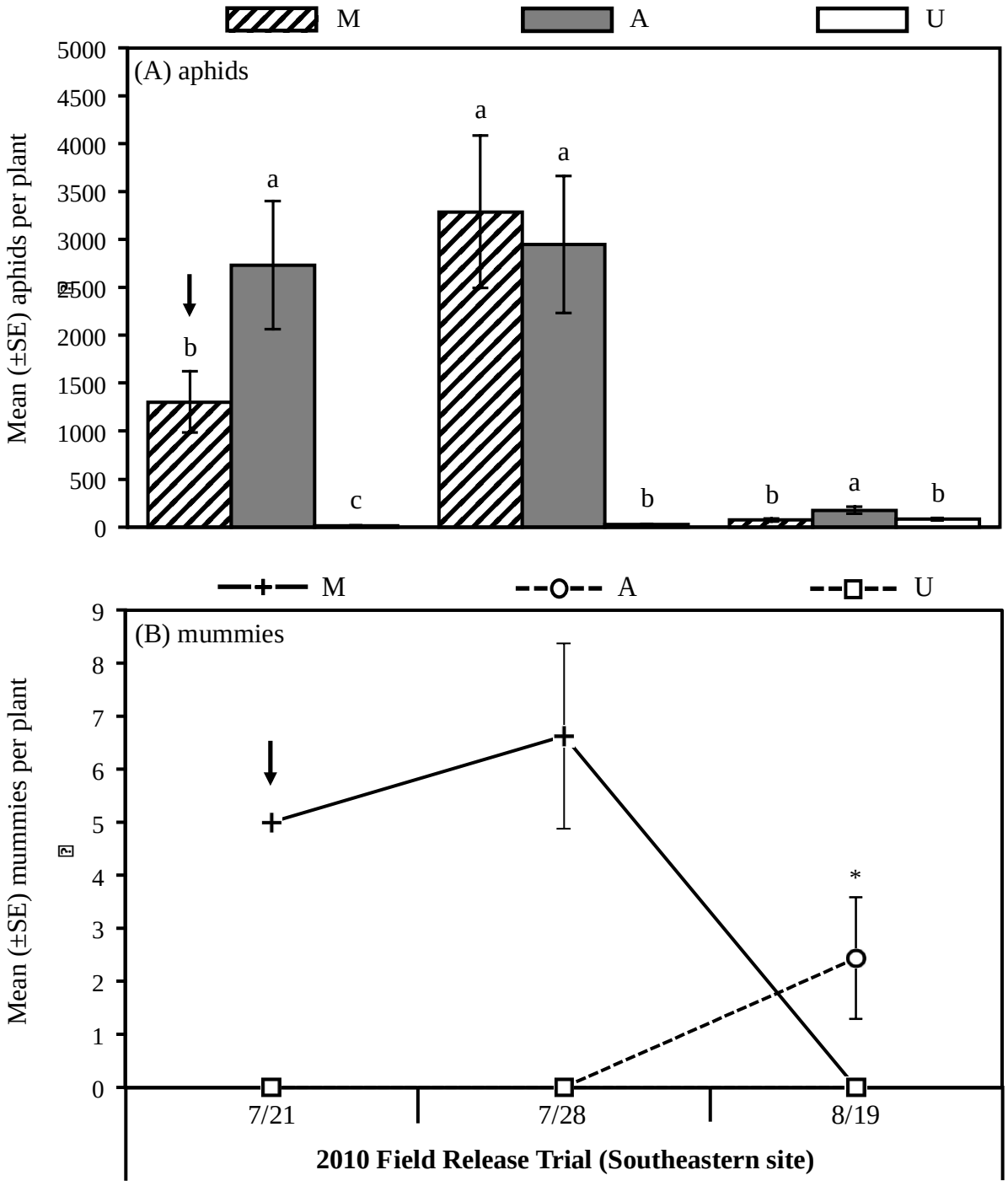

M
A
U
(A) aphids
Mean (±SE) aphids per plant
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
a
a
a
b
c
b
b
a
b
M
A
U
(B) mummies
Mean (±SE) mummies per plant
9
8
7
6
5
4
3
2
1
0
*
7/21
7/28
8/19
2010 Field Release Trial (Southeastern site)

Figure 12.

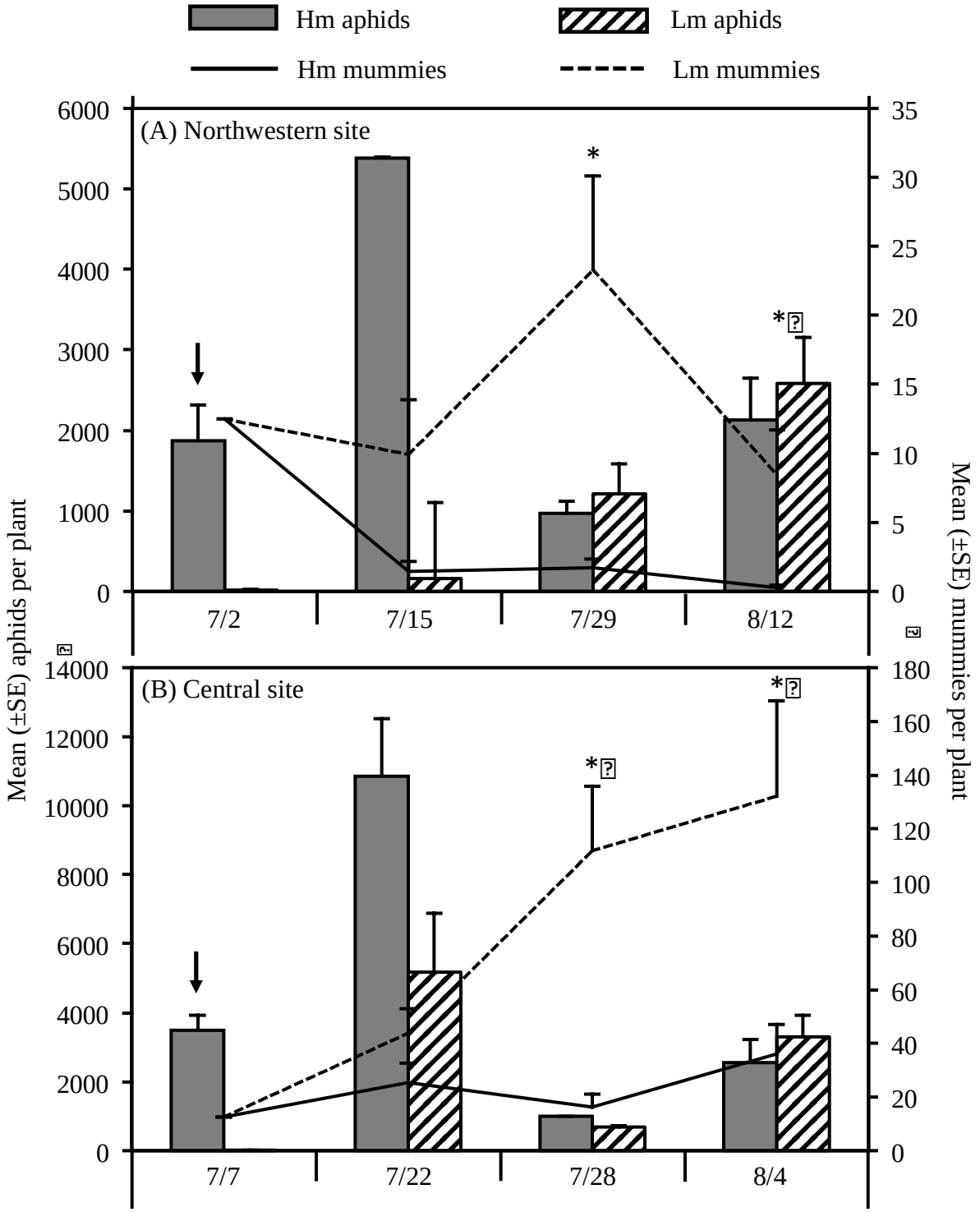
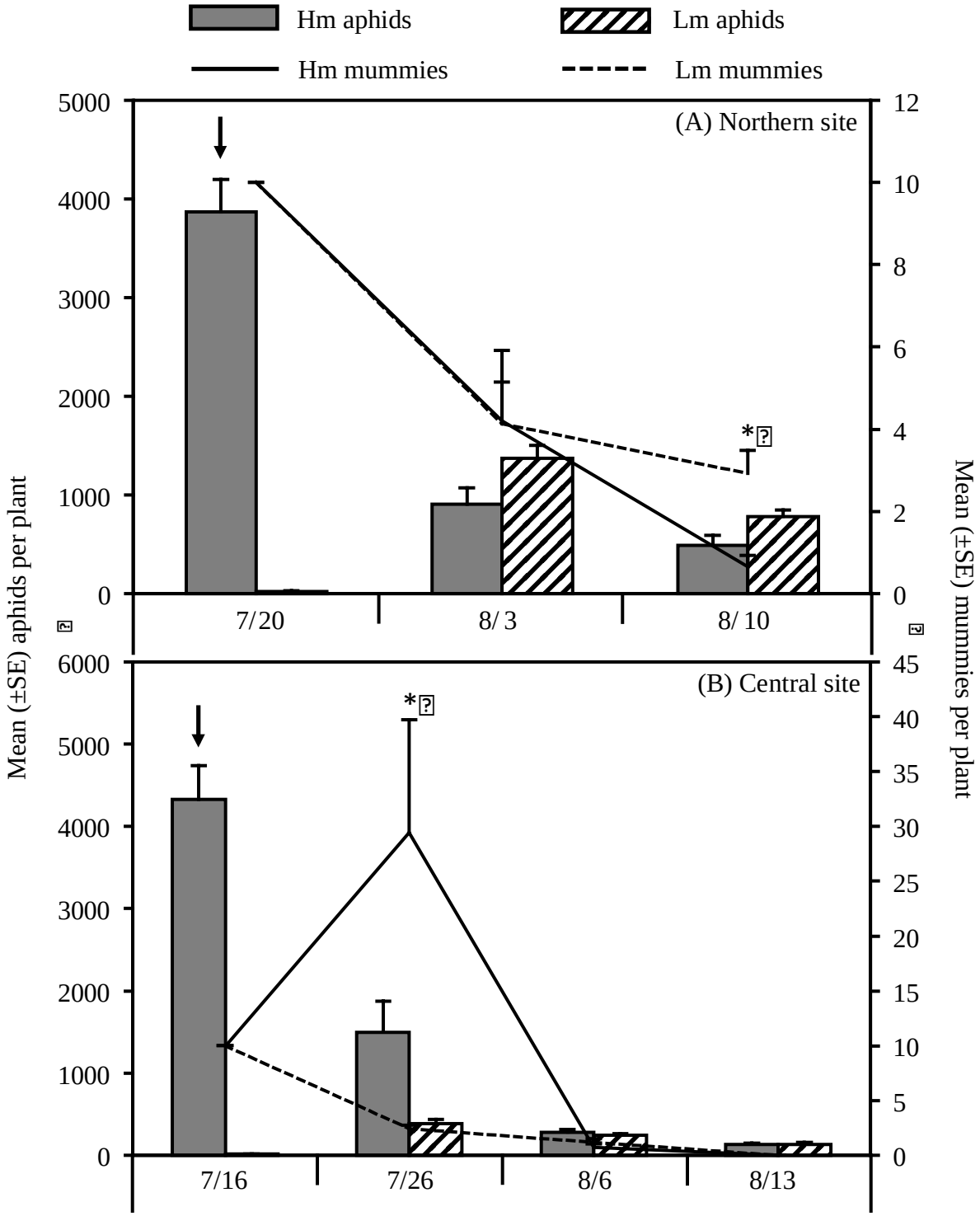

Hm aphids
Lm aphids
Hm mummies
Lm mummies
(A) Northwestern site
(B) Central site
Mean (±SE) aphids per plant
Mean (±SE) mummies per plant
7/2
7/15
7/29
8/12
7/7
7/22
7/28
8/4

Figure 13.


Hm aphids
Lm aphids
Hm mummies
Lm mummies
(A) Northern site
(B) Central site
Mean (±SE) aphids per plant
Mean (±SE) mummies per plant
7/20
8/3
8/10
7/16
7/26
8/6
8/13
*
5000
4000
3000
2000
1000
0
6000
12
10
8
6
4
2
45
40
35
30
25
20
15
5

Chapter III

Amount and placement of prairie conservation strips within annual crop systems to support beneficial arthropod communities

A paper to be submitted to *Environmental Entomology*

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Iowa State University,

Ames, IA 50011

Abstract

Non-crop habitat within and around farmland can provide several benefits to beneficial insects such as refuge from disturbance regimes and floral resources. The abundance and diversity of beneficial arthropods in cropland is affected by the size and distribution of adjacent non-crop habitat. To determine how the abundance and diversity of natural enemies, pollinators, and pests respond to the amount and placement of non-crop habitat, treatments consisting of varying amounts and distributions of prairie were established within catchments devoted to annual crop production. Arthropods were collected once a month (May through September) with a sweep-net in 2009 from soybean and prairie; in 2010, we sampled from corn with a vacuum and from prairie with a sweep-net. We collected nearly 60,000 arthropods, representing several taxa critical for pest regulation (e.g., Araneae, *Orius insidiosus*, Coccinellidae, and Syrphidae), pollinators, incidental arthropods, and pests. The abundance of natural enemies and pollinators varied significantly between crop and prairie. The abundance of natural enemies, pollinators, and pests was not significantly

affected by prairie treatment sizes and distributions within crop and prairie land cover. Specific natural enemy taxa that were significantly more abundant within prairie were Araneae, Syrphidae, Cantharidae, Braconidae, and *Coenosia* spp., while Coccinellidae and Nabidae were significantly more abundant within crop land cover. The abundance of *Orius insidiosus* by land cover type. Addition of native prairie species to annual crops within watersheds can be expected to benefit the abundance and diversity of various beneficial arthropods, without taking a significant chunk of cash crops out of production.

KEYWORDS**:** Conservation biological control, strip management, predators, parasitoids, natural enemies

Introduction

Diversification of plant species within agricultural ecosystems can promote ecosystem function, enhancing the delivery of many vital ecosystem services such as water purification and biological pest control (MEA 2005, Pascual and Perrings 2007). Conventional farm management is designed to maximize the delivery of provisioning services (e.g., food, fiber, and energy production) often at the expense of ecosystem function as a whole (Power 2010). Conventional farming systems currently depend on external inputs such as fertilizers and pesticides to compensate for the reduction of ecosystem function caused by excessive tillage, harvesting of crop residue, and the reduction of habitat diversity (Westmacott and Worthington 1997, Manhoudt and de Snoo 2003). Ecosystem function can be restored in part by increasing habitat diversity. For example, increasing habitat diversity in and around crop fields can increase the biological control of pests in annual cropping systems (Gurr et al. 2003, Tscharntke et al. 2007).

Non-crop habitats can provide plant-derived food resources (e.g., nectar or pollen), alternative prey, refuge from pesticides and other disturbances, shelter, a moderate microclimate (Dyer and Landis 1996) and hibernation sites (Landis et al. 2000) for natural enemies. Fiedler and Landis (2007) compared the attractiveness of 35 flowering species native to North American prairies to exotic plants recommended for habitat management. Overall, they observed that many native plant species more attractive to natural enemies than exotic species. The authors noted that native flowering species that were the most attractive to natural enemies could be combined to produce a mixture that could provide floral resources throughout the season. By recreating a prairie with these plant species, farmers may be able to attract and sustain natural enemies such that pest populations are kept low throughout the growing season. For example, Werling et al. (2012) found that by incorporating prairie grasses into a potato agroecosystem, predation of the Colorado potato beetle (*Leptinotarsa decemlineata*) by arthropods such as harvestmen (Opiliones) and spiders (Araneae) was increased fourfold.

This study was part of an interdisciplinary effort to quantify improvements in ecological function (e.g., water, nutrient, and carbon cycling) and biodiversity when prairie is strategically planted in various proportions and configurations within sub-watershed catchments dedicated to annual row-crop production. The overall objective, known as the STRIPs (Science-based Trials of Rowcrops Integrated with Prairies; see: STRIPs Research Team 2012) project is to test the hypothesis that incorporation of various percentages and distributions of prairie within these annual crops will result in disproportional improvements in ecological function, as well as abundance and diversity of wildlife and plants. My contribution to this interdisciplinary study was to determine how the diversity and abundance

of pest and beneficial arthropods (natural enemies and pollinating bees) is affected by the addition of prairie to catchments devoted to annual crop production.

Within this experiment we determined if economically important pest insects, natural enemies, and pollinating bees (hereafter referred to as pollinators) were more abundant within prairie or crop (hereafter referred to as land cover types). We first hypothesized that natural enemies, pollinators, and economic pests would be more abundant, and more diverse within prairie than in crop. Furthermore, we hypothesized that varying population dynamics would exist for key taxonomic groups of natural enemies throughout the season. Our second hypothesis was that the percentage and distribution of prairie land coverage within cropland committed to a corn-soybean rotation would increase the abundance of pests, pollinators and natural enemies within the adjacent crop.

Methods and Materials

Study site. This study was conducted in Jasper County in central Iowa, within the STRIPs research location at the Neal Smith National Wildlife Refuge (NSNWR). In multiple sub-watershed catchments (referred to as catchments herein) located within NSNWR, various proportions and distributions of prairie were restored horizontal to the slope of sub-watershed catchments (the smallest watershed management unit that drains an individual development site to its first intersection with a stream) devoted to a yearly-rotated soybean-corn crop system. The prairie land cover of our study consisted of historical restoration of tallgrass prairie and flowering forbs native to Iowa, referred to as prairie herein. Prairie restorations were consistent with other restorations within the NSNWR, wherein the ultimate goal of the refuge is to restore 3200 hectares within its boundaries. A mixture of > 20 species were

restored within each experimental sub-watershed catchment in 2007, dominated by Indiangrass [*Sorghastrum nutans* (L.) Nash], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and big bluestem (*Andropogon gerardii* Vitman) (Hirsh et al. 2013).

Experimental Design. To test our hypotheses regarding the impact of prairie on arthropod abundance and diversity we sampled communities from both the crop and prairie land cover types within the STRIPs project. This project consisted of twelve catchments within three sites, or blocks (referred to as Basswood, block 1; Interim, block 2; and Orbweaver, block 3) in which prairie was restored at the base of the catchment, or in a horizontal strip configuration along the contour of the catchments within row crops (Table 1; Fig. 1). These sub-watershed catchments were contained within the Walnut Creek watershed, which traverses 97 miles northwest of Des Moines, Iowa (see: Walnut Creek Watershed 2012). The crop system consisted of an annual soybean-corn (2009 and 2010 respectively) rotation. Treatments were established after tillage of the watersheds in 2007 and left untilled thereafter. Three replications of four treatments were randomized within twelve catchments in a randomized incomplete block design. Treatments consisted of the following percentages and distributions of prairie plant coverage within experimental catchments devoted to annual crop production: (1) 10% prairie at the base of the catchment, referred to as ‘10% toe’; (2) 10% prairie distributed between the base and upper contour positions, referred to as ‘10% strips’; (3) 20% prairie distributed between the base and upper contour positions, referred to as ’20% strips’; and (4) only annual crops, referred to as ‘all crop’ (Table 1; Fig. 1). Crop land cover consisted of soybean in 2009 and corn in 2010.

Arthropod sampling. We used two sampling methods to determine the community of arthropods in both prairie and crop land cover types. During 2009, sweep-nets (30.5 cm diameter) were used to sample arthropods in both prairie and soybean. At each catchment, three sweep-net samples were taken at three random locations within each prairie strip and at three random locations within the fifth row of soybean from the base of the catchment (Fig. 1). Each sample consisted of 20 continuous pendulum swings through the top 50% of the vegetation while walking forward, to collect aerial and foliar arthropods. Samples were taken once a month (May through September within prairie; June through September within soybean) between 1000 h and 1700 h at temperatures above 15° C with wind gusts less than 20 kph. Each sweep-net sample was placed into individual top-closure polyethylene bags, labeled according to its respective date, site, replication, and stored at -20° C for future identification.

During 2010, the prairie was sampled again with sweep-nets per the methods used in 2009. However, due to the difficulty of sampling corn with a sweep-net, corn was sampled using a modified leaf blower to suction arthropods from foliage. A fine mesh, white paint strainer was placed over the air intake on the leaf blower (Troy-Bilt, Model# TB320BV, Cleveland, Ohio), set to vacuum (adapted from Fiedler and Landis 2007), and each paint strainer was placed into separately labeled plastic bags. Three random vacuum samples were taken within the fifth row of corn planting of each catchment at a consistent pace for forty seconds (approximately the same duration for a sweep-net sample). Samples were taken once a month (May through September within prairie; June through August within corn) between 1000 h and 1700 h at temperatures above 15° C with wind gusts less than 20 kph.

Arthropod Identification. Arthropod samples were sorted and stored -20° C and retained for further analysis. All arthropods were identified to at least family (Triplehorn and Johnson 2005) and lower taxonomic rank according to the availability of time and suitable keys, except in the case of severely damaged specimens, early instars, Acari, Araneae, Collembola, Lepidoptera, Opiliones, Psocoptera, and Thysanoptera. Following identification, arthropods were characterized into the following groups relevant to agriculture for analyses: pests (economically important pests of soybean [(Lorenz et al. 1999, Copes 2010) or corn (O'Day et al. 1998)], natural enemies (predators and parasitoids), bees (pollinating Apoidea, excluding parasitic species), and incidental arthropods (all detritivores, and herbivores not characterized as economic pests of soybean or corn).

Refer to Appendix B1 and B2 for the full list of natural enemies collected in 2009 and 2010, respectively. Refer to Appendix B3 and B4 for full list of soybean pests collected in 2009 and 2010, respectively. Refer to Appendix B5 and B6 for full list of incidental arthropods collected in 2009 and 2010, respectively. Refer to Appendix B7 and B8 for the full list of pollinators collected in 2009 and 2010, respectively.

Data Analysis. Abundance of arthropod taxa were summarized by land cover type and treatment, and reported as means. All data were $\log_e (x+1)$ transformed to correct for skewness and heterogeneous variances. For all analyses, assumptions of normality and equal variance were verified using residual plots, Shapiro-Wilk test of normality (Shapiro and Wilk 1965), and Bartlett's test of equal variance (Snedecor and Cochran 1989).

Effects of Land Cover Type on Arthropod Abundance and Diversity. To test our hypothesis that the abundance of arthropods (natural enemies, pollinators, and pests) varies

between crop and prairie land cover type, data were pooled across all sampling dates from 2009. A two-way analysis of variance (ANOVA) within the general linear model procedure (PROC GLM; SAS Institute 2004) was conducted including the factors block, land cover, and their interaction. Data were analyzed separately for each response variable (mean natural enemies, pollinators, and economically important crop pests). Multiple comparisons of land cover and block were conducted using the Tukey-Kramer HSD method of all significant factors at alpha 0.05 level. In addition, only the 2009 dataset was used to compare land cover type, since the vacuum sampling technique used to sample arthropods within corn in 2010 did not capture the same types of arthropods, abundance of arthropods, or species richness.

The same analysis was conducted for taxa comprising 90 % of the natural enemy community, which amounted to eight taxa. Each of the eight most commonly collected natural enemy taxa per sweep-net sample for each catchment (experimental unit) were used as explanatory variables. To determine the effect of land cover type at each sampling date throughout the season, of each of the eight most abundant natural enemy taxa, a two-way mixed model (PROC MIXED; SAS Institute 2004) ANOVA was conducted for each taxa separately. Treatment, block, month, and the month by land cover interaction were treated as fixed effects, while the block by treatment interaction was treated as a random effect. Least-square means tests on simple effects were computed on sliced data when first order interactions were detected (i.e., land cover differences for each month when month by land cover interactions were detected).

To provide a measure of arthropod diversity within each land cover type, we used Shannon's diversity index (H′) (Hill 1973). Because H′ is a heterogeneity index which tends to be sensitive to rare species (Peet 1974), we also calculated an equitibility indix of evenness

($E = H'/H_{max}$) to provide a measure of the distribution of abundance across species. To assess arthropod community similarity between prairie and crop land cover type, we measured the similarity among replicated communities using the Steinhaus similarity index for each guild and year separately (S_{ij}) (Legendre and Legendre 1998). The Steinhaus index is the complement of the Bray-Curtis index ($S_{ij} = 1 - BC$). Bray-Curtis dissimilarity values were calculated using vegdist within the vegan package (R Development Core Team 2011) on arthropod relative abundance data, in order to account for the sampling bias between prairie and crop.

Effects of Prairie Treaments on Arthropod Abundance. To test our hypothesis that arthropod (natural enemies, pollinators, and economically significant crop pests) abundance would vary depending on prairie treatments (10% toe, 10% strips, 20% strips, and all crop), data were pooled across all sampling dates within each year. A one-way ANOVA within the general linear model procedure (PROC GLM; SAS Institute 2004) was conducted using the factors treatment and block. Data were analyzed separately for each year (2009 and 2010), land cover type (crop and prairie) and response variable (mean natural enemies, pollinators, and pests). A second analysis (two-way ANOVA) was conducted, adding the factor land cover type, and the interaction of land cover and treatment. This analysis was only conducted for the 2009 dataset, because the technique was the same between land cover types. Multiple comparisons across treatment were conducted using the Tukey-Kramer HSD method of all significant factors at alpha 0.05 level. Pairwise comparisons of land cover by treatment were conducted using lsmeans tests for significant interaction effects for 2009 dataset.

Results

Arthropod Abundance and Diversity. Throughout the 2009 and 2010 field seasons 25,353 and 29,385 arthropods were collected, respectively. A total of 8,174 predaceous and parasitoid specimens (natural enemies) were collected in 2009, representing 60 families and 156 species (Appendix B1), in contrast with 7,042 natural enemies collected in 2010 representing 59 families and 145 species (Appendix B2). Over half of the natural enemy families belonged to Hymenoptera (32 families in 2009 and 30 families in 2010). A total of 7,740 economic pests were collected in 2009, representing 16 families and 27 species (Appendix B3); 2,165 economic pests were collected in 2010, representing 10 families and 19 species (Appendix B4). A total of 9,432 incidental arthropods were collected in 2009, representing 73 families and 146 species; 21,982 incidental arthropods were collected in 2010, representing 83 families and 199 species. A total of 221 pollinators were collected in 2009, representing 8 families and 10 species; 335 pollinators were collected in 2010, representing 8 families and 11 species. The lowest species richness was recorded within corn in 2010 (81 species), and the highest species richness was recorded in prairie in 2010 (323 species).

Effects of Land Cover Type on Arthropod Abundance and Diversity. The species richness and diversity of each guild (natural enemies, pests, incidental arthropods, and pollinators) was greater in prairie than crop. In 2009, the natural enemy, pest, and pollinator community was more even within prairie than soybean; whereas, only the incidental arthropod communities were more even within soybean than prairie. In 2010, nearly the opposite effect was found. Only the pest community was more even within prairie than corn;

whereas, the natural enemy, pollinator, and incidental arthropod communities were more even within corn. Overall, the athropod community between land cover types was more similar in 2009 than 2010, when the cropland was planted with soybean instead of corn. Of all of the guilds collected in both years, the natural enemy and pest communities in 2009 were the most similar (Table 2).

The abundance of arthropods between prairie and crop land cover varied by guild in 2009, the only year that the same sampling method was used so we could directly compare arthropod abundance in each land cover type. Abundance of natural enemies varied significantly by land cover (F = 10.77; df = 1, 15; P = 0.005), and prairie contained significantly more natural enemies (22.95 ± 2.66) over the entire season than crop (14.98 ± 1.32). Abundance of pollinators also varied significantly between prairie and crop (F = 58.21; df = 1, 15; P < 0.001), with with prairie land cover (0.82 ± 0.12) containing nearly ten-fold more pollinators than the crop (0.07 ± 0.02). The abundance of pests did not vary by land cover type (F = 0.00; df = 1, 15; P = 0.987).

Most Commonly Collected Natural Enemy Taxa Within Crop and Prairie. In 2009, eight taxa accounted for 90 % of the natural enemy community collected in both land cover types. Within these eight taxa, seven varied significantly between the two land cover types (Araneae: F = 47.86; df = 1, 15; P < 0.001; Syrphidae: F = 108.64; df = 1, 15; P < 0.001; Coccinellidae: F = 52.11; df = 1, 15; P < 0.001; Cantharidae: F = 147.55; df = 1, 15; P < 0.001; Braconidae: F = 123.39; df = 1, 15; P < 0.001; Nabidae: F = 24.84; df = 1, 15; P = 0.002; *Coenosia* spp.: F = 31.32; df = 1, 15; P < 0.001), Five taxa were more frequently captured in prairie then soybean (Araneae, Syrphidae, Cantharidae, Braconidae, and

Coenosia spp.). Only Coccinellids and Nabids were more abundant within soybean than prairie. *Orius insidiosus* (Say) was frequently captured in both prairie and soybean and its abundance did not vary significantly between the two land cover types ($F = 0.02$; df = 1, 15; $P = 0.891$) (Table 3).

Each taxa exhibited unique population dynamics between the two land cover types throughout the season in 2009. A significant month by land cover interaction was observed for each of natural enemy taxa: Araneae ($F = 5.63$; df = 3, 29; $P = 0.004$), Syrphidae ($F = 7.46$; df = 3, 29; $P < 0.001$), *O. insidiosus* ($F = 15.23$; df = 3, 29; $P < 0.001$), Coccinellidae ($F = 26.00$; df = 3, 29; $P < 0.001$), Cantharidae ($F = 22.67$; df = 3, 29; $P < 0.001$), Braconidae ($F = 3.40$; df = 3, 29; $P = 0.031$), Nabidae ($F = 6.77$; df = 3, 29; $P = 0.001$), and *Coenosia* spp. ($F = 19.32$; df = 3, 29; $P < 0.001$). In June, Araneae, Syrphidae, Cantharidae, and Braconidae were most abundant within prairie, whereas no natural enemy taxa were significantly more abundant within crop (Fig. 2). During August and September, only Aranaeae, Syrphidae, and Cantharidae were consistently more abundant within prairie. Certain natural enemy families were significantly more abundant within crop later in the season (August and/or September), such as *O. insidiosus*, Coccinellidae, Nabidae, and Braconidae. Excluding Coccinellidae and Nabidae, significantly more natural enemies were found within prairie in September, likely due to the senescence of soybean (Fig. 2). Comparisons were not made in May, since arthropods were not collected from soybean due to the inability to sweep short plants in early vegetative stages (V1-V3). Prairie strips were mowed in July 2009, per recommendation of NSNWR staff; therefore, analyses from this collection date are not discussed.

Effects of Prairie Treatments on Arthropod Abundance. The size and distribution of prairie treatments did not significantly affect the abundance of natural enemies, pests, or pollinators within prairie or crop in 2009 or 2010. Natural enemy abundance in 2009 was not significantly affected by treatment within prairie (F = 3.46; df = 2, 4; P = 0.134), or crop (F = 0.12; df = 3, 6; P = 0.945) (Fig. 3a). In 2010, natural enemy abundance was not significantly affected by treatment within prairie (F = 1.29; df = 2, 4; P = 0.370), or crop (F = 1.53; df = 3, 6; P = 0.301) (Fig 3b). Pest abundance in 2009 was not significantly affected by treatment within prairie (F = 0.00; df = 2, 4; P = 0.999), or crop (F = 2.45; df = 3, 6; P = 0.162) (Fig. 4a). In 2010, pest abundance was not significantly affected by treatment within prairie (F = 1.15; df = 2, 4; P = 0.402), or crop (F = 1.88; df = 3, 6; P = 0.233) (Fig. 4b). Pollinator abundance in 2009 was not significantly affected by treatment within prairie (F = 0.33; df = 2, 4; P = 0.736), or crop (F = 0.92; df = 3, 6; P = 0.488) (Fig. 5a). In 2010, pollinator abundance was similarly not affected by treatment in prairie (F = 0.33; df = 2, 4; P = 0.736), or crop (F = 0.54; df = 3, 6; P = 0.673) (Fig. 5b).

One treatment level did not contained prairie (i.e., all crop treatment). Therefore, interactions between treatment and land cover type were not accurately estimated for the overall model, and will not be presented. We overcame this hurdle in our statistical model by estimating pairwise comparisons between land cover types for each treatment in 2009. Natural enemies were significantly more abundant within prairie land cover within treatment 2 and 3; but equally abundant within both land cover types for treatment 1 (Fig.3a). Pest abundance did not differ between land cover types for any of the treatments (Fig. 4a). The

abunance of pollinators was significantly higher within prairie for all treatment levels (Fig. 5a).

Discussion

These results suggest that tallgrass prairie can enhance the diversity and abundance of arthropods within catchments devoted to annual crop production. Prairie supported a far greater abundance of natural enemies and pollinators than crop land cover; however, pest abundance did not differ between the two land cover types. Prairie contained a greater abundance of arthropods (Appendices B1-B8), more species, and higher species diversity than crop (Table 2). It is to be expected that arthropod abundance, species richness, and species diversity would be greater within prarie than crop due to an increase in habitat diversity. The similarity of the arthropod community in prairie versus crop was much higher when soybean was planted as compared to when corn was planted. This is likely due to the fact that sweep-nets were used to collect arthropods in soybean and prairie, whereas vacuum samples were taken within corn. Thus, conclusions cannot be made about the similarity in the arthropod community between soybean and corn. It is interesting that the natural enemy and pest communities were fairly similar between soybean and prairie. This may be due to an influx of natural enemies in response to prey, which is discussed in greater detail below. It should be noted that pest species were not sampled in a way to determine whether they were at economically damaging levels, and the list of pests encompasses various pest species that may not be considered as economically important in various regions of the US and the world.

Natural enemy abundance differed between the two landcover types, and this difference varied by taxa. Of the natural enemy taxa that comprised 90% of the individuals

collected, six were significantly more abundant within prairie (Araneae, Syrphidae, Cantharidae, Braconidae, *Coenosia* spp., and Eulophidae). Many natural enemies require non-crop habitat to some extent (Landis et al. 2005, Duelli and Orbist 2003, Bianchi et al. 2006), and must move between land cover types to sustain populations (Wissinger 1997). For example, adult Syrphidae and Cantharidae feed on pollen and nectar and therefore likely benefited from the addition of flowering plants in the prairie strips (Frank 1999, Oaten et al. 2008). *Orius insidiosus* was not significantly more abundant within either land cover type. This is not surprising, as *Orius insidiosus* is a facultative herbivore, capable of surviving on plant material in the absence of insect prey (Coll 1996). Its populations peaked within crop in August, but within prairie in September. This suggests that *O. insidiosus* colonizes soybean based upon prey availability, and prairie for alternative prey or plant-provided resources later in the season. Lundgren et al. (2009) found *O. insidiosus* to be more abundant within vegetationally diverse cropland than in sobybean monocultures. They also found that females laid twice as many eggs on non-crop plants as on soybeans. Our observations build upon these findings, in that that *O. insidiosus* may utilize either habitat depending on the resources that are available when crop is adjacent to prairie. Coccinellidae and Nabidae were significantly more abundant within soybean than the prairie. Nabidae are polyphagous generalist natural enemies, and are frequently found in soybean fields (Evans 1985, Schmidt et al. 2008). The greater abundance of coccinellids within soybean may be explained their tendency to track their prey (i.e., the soybean aphid, *Aphis glycines* Matsumura) into various habitats (Leather and Owour 1996). Interestingly, four of the eight most commonly collected natural enemies within both land cover types in 2009 are considered important natural enemies of the soybean aphid (*O. insidiosus*, Coccinellidae, Syrphidae, and Nabidae). The

seasonal abundance of three of these natural enemy taxa substantially increased within soybean in August, after *A. glycines* had likely arrived. (Figs. 2b,2c,2f). Schmidt et al. (2012) summarized the spatial distribution of *A. glycines* through the suction trap network, and found that the peak in *A. glycines* alates occurred late July to mid-August. The arrival of soybean aphid indicated by suction traps located approximately 96 km north of the NSNWR (2 aphids collected on 24 July; 19 collected on 31 July) coincides with the collection of soybean aphids within our study (1 soybean aphid collected on 1 July 2009, and 76 soybean aphids collected on 1 August 2009; total aphid counts, Appendix B3). These observations suggest that prairie may serve as a source of actively dispersing natural enemies into soybean when a pest population increases. Syrphids are considered predators of *A. glycines*, but their abundance was consistently higher in prairie than soybean, even in August. This unresponsivness may be a result of sweep net's sampling the adults and not the predatory life stage. Finally, the abundance of these taxa considered important for *A. glycines* mortality could contribute to the species similarity between soybean and prairie was higher than the similarity between prairie and corn.

Overall, the percentage and distribution of prairie within the catchments did not affect the abundance of beneficial insects, specifically natural enemies or pollinators in either prairie or the crop (Figures 3 and 5 respectively). We anticipated that prairie within the catchments would increase the abundance beneficial insects within the adjacent crop. However, the total abundance of these arthropods within the crop was not affected by the amount or distribution of prairie within the catchment. Even though prairie did not increase the abundance of arthropods in the adjacent crop, prairie did contain more arthropods than the crop. During 2009, in which the same sampling method was used in both the prairie and

the crop, regardless of the configuration or amount of prairie, more pollinators were found in the prairie than the crop. More natural enemies were found in the prairie than the crop for catchments with 10% and 20% strips of prairie, but not the catchment with only 10% prairie at the toe.

This lack of an effect of prairie on the abundance of beneficial insects in the crop portion of the catchments may be due to variation in the response of individual species. As noted in Figure 2, the response of natural enemies to prairie and soybean varied by species and by month. Some species, like *Orius insidiosus* (Fig. 2b), appeared to utilize prairie as an overwintering site from which they colonized the soybean field in August, returing to the prairie when the soybean senesced. Therefore, if prairies are considered for increasing the delivery of insect-derived ecosystem servives, assessing their value as a source of beneficial insects may require a focused analysis on specific taxa of interest.

As noted by Helmers et al. (2012), the incorporation of prairie within these catchments reduced sediment and nutrient loss. Therefore, there is value in employing prairie within watersheds committed to annual crop production. Although prairies did not consistently increase the abundance or diversity of beneficial insects in the adjacent crop, these results do support the use of prairie as a means to increase biodiversity and ecosystem service delivery to catchments committed to a corn-soybean rotation. First, prairie increases the biodiversity of beneficial insects compared to land used for corn or soybean production. Consistently more species, and overall more individual natural enemies and pollinators were found in prairie than the crop. The incorporation of small amounts of prairie was just as effective at increasing the abundance of beneficial arthropods as the incorporation of large amounts of prairie. Finally, the incorporation of prairie did not put the crop system at a

greater risk of pest colonization. In both years we did not observe an effect of the prairie treatments on the abundance of pests in the crop (Fig. 4). In 2009, when the same sampling method was used in prairie and soybean, we did not observe a difference in the abundance of pests between prairie or crop for any of the treatments. Overall, these observations suggest that prairie did not harbor more pests or increase the risk of pest exposure to the adjacent crop.

In conclusion, the inferences drawn from this experiment should consider the experimental design and the matrix in which it was conducted. The experiment was initially designed to investigate the impact of varying amounts and configurations of prairie on factors related to watershed management (i.e. soil erosion, nutrient loss, etc.). The block design with experimental units adjacaent to each other may not be suitable for detecting the effect of prairie on the abundance of mobile arthropods. For example, the inability to detect more natural enemies within the crop of catchments with prairie compared to catchments with only crop may have been due to the close proximity of catchments integrated with prairie to the catchments with only crop. Had the experimental units been farther apart, the impact of prairie within a catchment on the adjacent crop may have been greater than what was observed. Furthermore, the community of arthropods that were sampled is likely a product of the surrounding matrix in which the experiment was conducted. All blocks were located within the NSNWR, which, when the experiment was conducted, consisted of 2,023 ha of reconstructed prairie within the refuge's boundaries (approximately 3200 ha). It's not surprising that differences in arthropod abundance were difficult to detect, due to the magnitude of our experimental units in comparison to the expansive matrix of prairie and forest within the refuge. The matrix of the NSNWR is not typical for Iowa, as less than

0.01% of the original prairie remains. It is likely that the response of arthropods to the inclusion of prairie within a matrix dominated by annual crop production would differ from what we observed.

It would be extremely valuable to know how arthropods respond to similar treatments within a matrix dominated by crop. Future studies should examine arthropod abundance and pest predation with similar prairie treatments dominated by a cropland matrix.

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Table 1. Details of each experimental catchment, and the treatments applied to each within the STRIPs project at the Neal Smith National Wildlife Refuge

Block	Size (ha)	Slope (%)	Treatment (location and percent prairie)	Treatment Abbreviation
1 – 1 [a]	0.53	7.5	10% at toe slope	10% toe
1 – 2	0.48	6.6	10% on contour (5% toe slope, 5% up slope)	10% strips
1 – 3	0.47	6.4	20% on contour (10% toe slope, 10% up slope)	20% strips
1 – 4	0.55	8.2	20% on contour (10% toe slope, 10% up slope)	20% strips
1 – 5	1.24	8.9	10% on contour (5% toe slope, 5% up slope)	10% strips
1 – 6	0.84	10.5	100 % soybean (2009) or corn (2010)	all crop
2 – 1	3.00	7.7	10% on contour (3.3% toe slope, 3.3% side slope, 3.3% up slope)	10% strips
2 – 2	3.19	6.1	10% at toe slope	10% toe
2 – 3	0.73	9.3	100 % soybean (2009) or corn (2010)	all crop
3 – 1	1.18	10.3	10% at toe slope	10% toe
3 – 2	2.40	6.70	20% on contour (6.7% toe slope, 6.7% side slope, 6.7% up slope)	20% strips
3 – 3	1.24	6.60	100 % soybean (2009) or corn (2010)	all crop

Modified from Ohde (2012).

[a] Second number following block represents the catchment number.

Table 2. Species diversity of arthropod guilds collected from prairie and crop collected within the STRIPs project in 2009 and 2010

Guild: sampling year[a]	Prairie[b]	Crop[c]	Sum
Natural enemies: 2009			
Species richness (S) [b]	141	66	147
Shannon's diversity index (H′) [d]	3.06	2.31	
Percent similarity (S_{ij})			44.02%
Natural enemies: 2010			
Species richness	147	34	145
Shannon's diversity index	3.03	2.66	
Percent similarity			12.06%
Pests: 2009			
Species richness	32	24	33
Shannon's diversity index	2.64	1.49	
Percent similarity			44.17%
Pests: 2010			
Species richness	20	9	20
Shannon's diversity index	2.35	0.01	
Percent similarity			5.36%
Incidental arthropods: 2009			
Species richness	138	82	148
Shannon's diversity index	3.33	3.07	
Percent similarity			38.22%
Incidental arthropods: 2010			
Species richness	194	48	198
Shannon's diversity index	3.12	2.43	
Percent similarity			12.47%

Table 2. continued

Guild: sampling year[a]	Prairie[b]	Crop[c]	Sum
Pollinators: 2009			
Species richness	10	2	10
Shannon's diversity index	1.32	0.33	
Percent similarity			15.49%
Pollinators: 2010			
Species richness	11	1	11
Shannon's diversity index	1.02	0.00	
Percent similarity			13.55%
Overall (2009 & 2010)			
Species richness	448	197	463
Shannon's diversity index	4.03	3.26	
Percent similarity			42.00%

[a] Four main guilds (natural enemies, pests, incidental arthropods, and pollinators) collected at the STRIPS research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPS= Science-based Trials of Rowcrops Integrated with Prairies.

[b] Species richness calculations are additive over all treatments, sampling dates (once per month May through September 2009), prairie strip partition (1 to 3 strip partitions may be found within each catchment), and sample repetition (each prairie strip was sampled in three random locations, and each row-crop was sampled in three random locations within the fifth row from the base of soybean in 20009 and corn in 2010 plantings within each catchment).

[c] Arthropods were collected from soybean in 2009, and corn in 2010.

[d] See methods for calculations of diversity indices (H', and S_{ij}).

Table 3. Abundance of most commonly collected natural enemy taxa by land cover

	Prairie			Soybean		
Taxon[a]	Mean[b]	±	SE	Mean	±	SE
Araneae	5.87	±	0.62 * [c]	1.31	±	0.16
Orius insidiosus	3.76	±	0.63	2.74	±	0.34
Coccinellidae	1.19	±	0.24	6.26	±	0.70 *
Syrphidae	2.95	±	0.29 *	0.31	±	0.06
Cantharidae	1.98	±	0.33 *	0.06	±	0.02
Braconidae	1.44	±	0.14 *	0.24	±	0.05
Nabidae	0.54	±	0.07	1.31	±	0.14 *
Muscidae (*Coenosia* spp.)	0.77	±	0.13 *	0.15	±	0.04

[a] Natural enemy taxa are arranged from top to bottom as the most commonly collected taxa (90%) over both land cover types (prairie and soybean) per sweep-net sample over the entire season.

[b] Natural enemies per sweep-net sample. Arthropods averaged over all treatments, sampling dates (once per month May through September 2009), prairie strip partition (1 to 3 strip partitions may be found within each catchment), and sample repetition (each prairie strip was sampled in three random locations, and each row crop was sampled in three random locations within the fifth row from the base of soybean planting within each catchment).

[c] Analyses conducted on each natural enemy taxa separately. Significant differences in natural enemy taxa between land cover type (prairie and soybean) denoted by '*' (Tukey's HSD, $\alpha = 0.05$).

Figure Legends

Fig. 1. Location of experimental catchments within their respective blocks at the Neal Smith National Wildlife Refuge. Magnified box depicts where samples were randomly taken within each experimental catchment for block 3, and their respective treatments. See Table 1 for a full list of treatments applied to each experimental catchment.

Fig. 2. Natural enemies (mean total ± SEM) per sweep-net across all sampling dates in 2009, representing the most commonly collected natural enemy taxa. Significant differences in arthropod abundance between the two land cover types (prairie and soybean) are denoted by '*' ($P \leq 0.05$).

Fig. 3. Natural enemies (mean seasonal total ± 95% CI) collected in crop and prairie land cover within catchments with varying amounts of prairie. Crop land cover was soybean in 2009 (a) and corn in 2010 (b). Arthropods were collected in prairie and soybean with a sweep-net, and collected with a modified leaf-blower in corn. We observed no significant differences in the abundance of natural enemies within either land cover type across the four experimental catchments based on Tukey's HSD comparisons of $\log_e (x+1)$ transformed natural enemies ($\alpha = 0.05$). We denoted significant differences between the two land cover types within a treatment with '*' (lsmeans, $P \leq 0.05$). Means and confidence intervals in figure are $\log_e (x+1)$ back-transformed.

Fig. 4. Pests (mean seasonal total ± 95% CI) collected in crop and prairie land cover within catchments with varying amounts of prairie. Crop land cover was soybean in 2009 (a) and corn in 2010 (b). Arthropods were collected in prairie and soybean with a sweep-net, and collected with a modified leaf-blower in corn. We observed no significant differences in the abundance of pests within either land cover type across the four experimental catchments based on Tukey's HSD comparisons of $\log_e$ (x+1) pests (α = 0.05). Means and confidence intervals in figure are $\log_e$ (x+1) back-transformed.

Fig. 5. Pollinators (mean seasonal total ± 95% CI) collected in crop and prairie land cover within catchments with varying amounts of prairie. Crop land cover was soybean in 2009 (a) and corn in 2010 (b). Insects were collected in prairie and soybean with a sweep-net, and collected with a modified leaf-blower in corn. We observed no significant differences in the abundance of pollinators within either land cover type across the four experimental catchments based on Tukey's HSD comparisons of $\log_e$ (x+1) pollinators (α = 0.05). We denoted significant differences between the two land cover types within a treatment with '*' (lsmeans, $P \leq 0.05$). Means and confidence intervals in figure are $\log_e$ (x+1) back-transformed.

Figure 1.

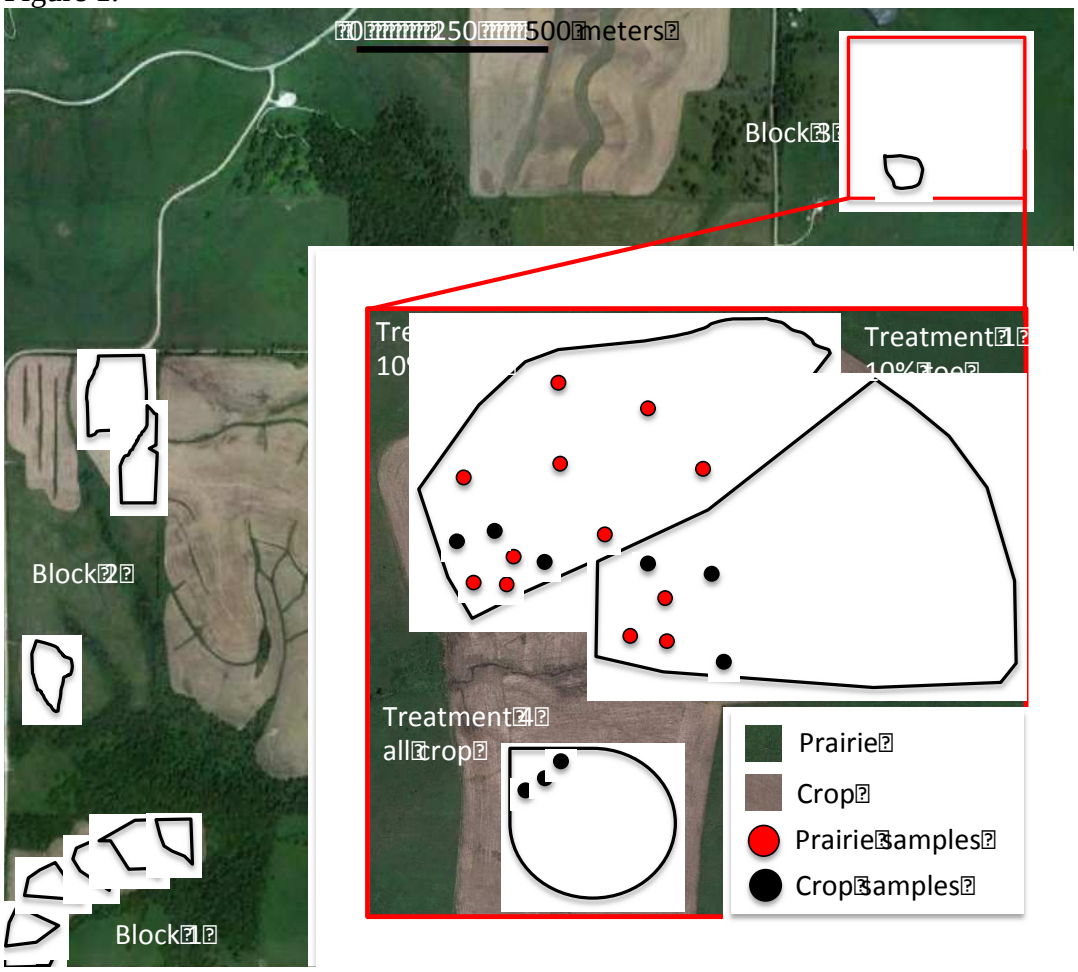

0 250 500 meters
Block 3
Block 2
Block 1
Treatment 1
Treatment 4
all crop
Prairie
Crop
Prairie samples
Crop samples

Figure 2.

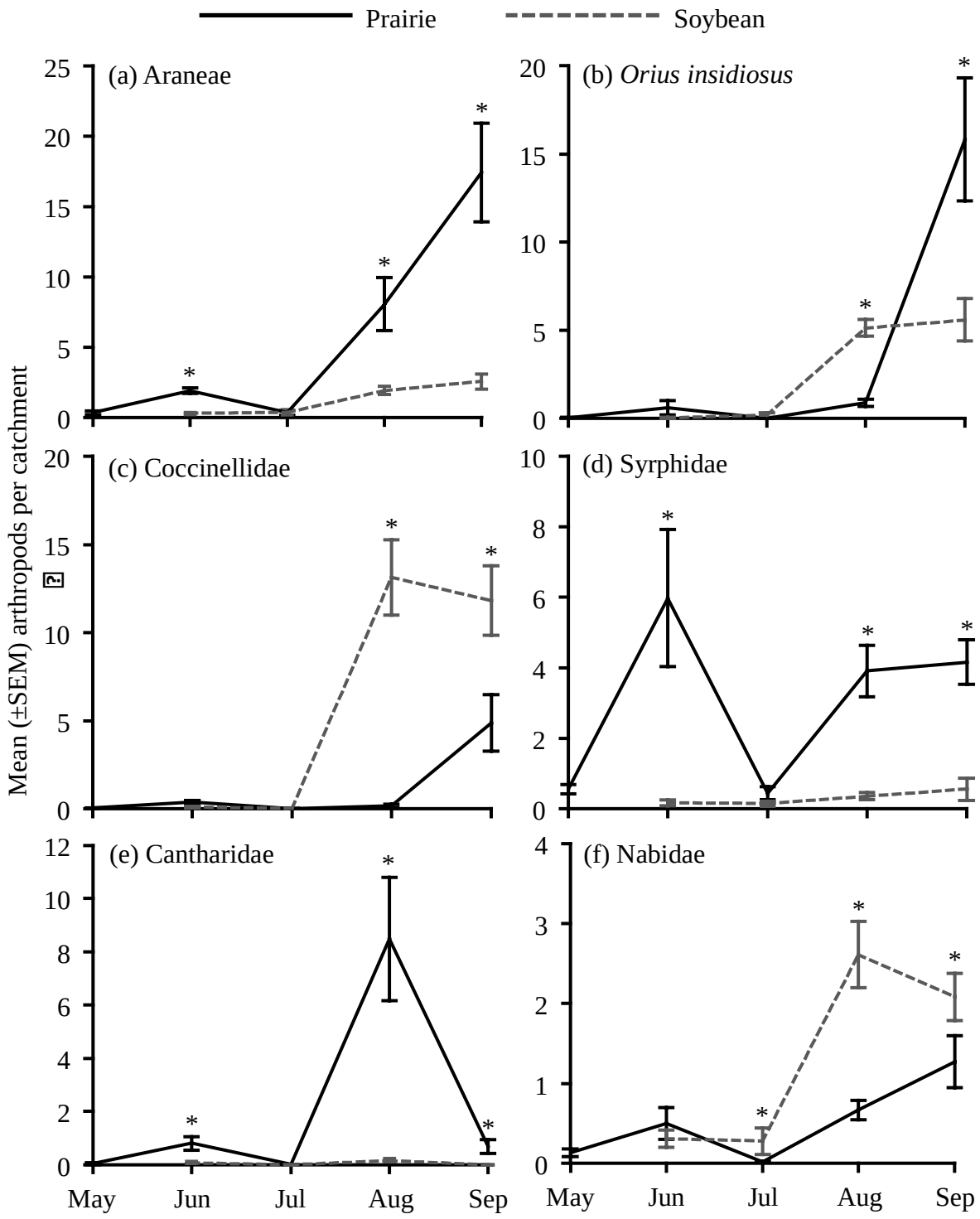

Prairie
Soybean
(a) Araneae
(b) *Orius insidiosus*
(c) Coccinellidae
(d) Syrphidae
(e) Cantharidae
(f) Nabidae
Mean (±SEM) arthropods per catchment
May
Jun
Jul
Aug
Sep

Figure 2 continued.

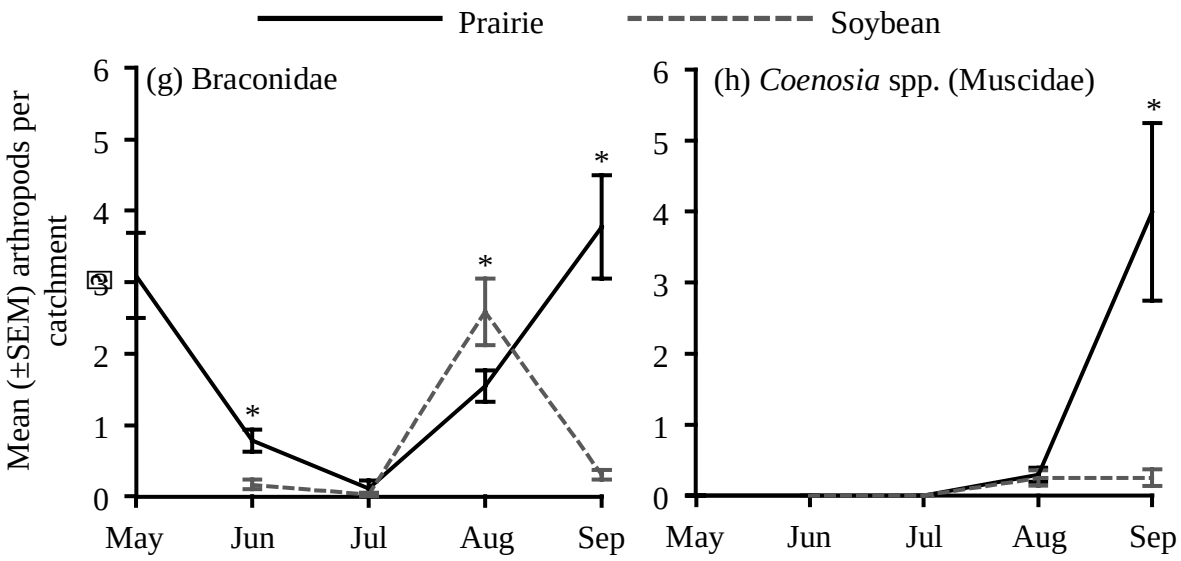


Figure 3.

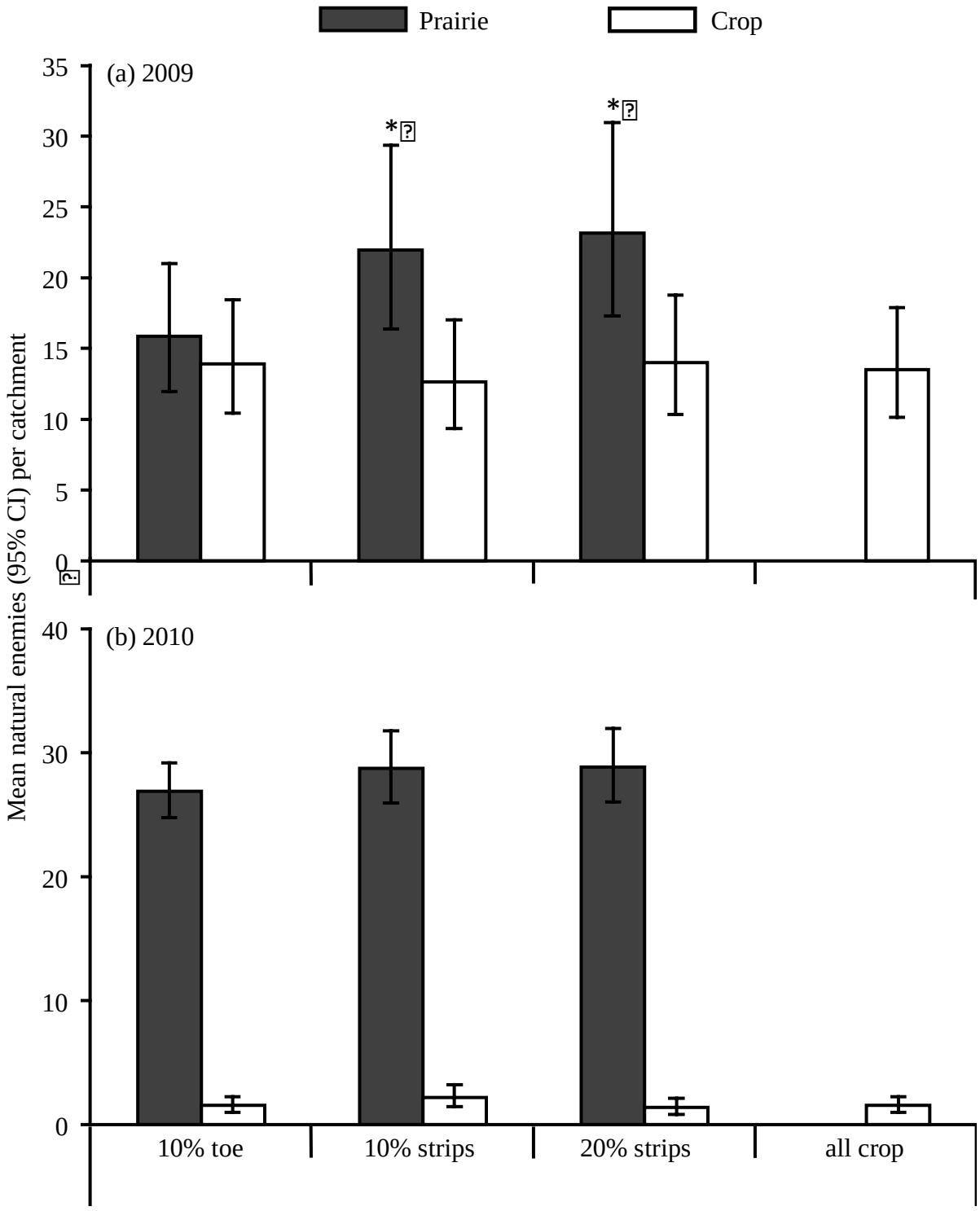

Prairie
Crop
(a) 2009
(b) 2010
Mean natural enemies (95% CI) per catchment
35
30
25
20
15
10
5
0
40
30
20
10
0
*
*
10% toe
10% strips
20% strips
all crop

Figure 4.

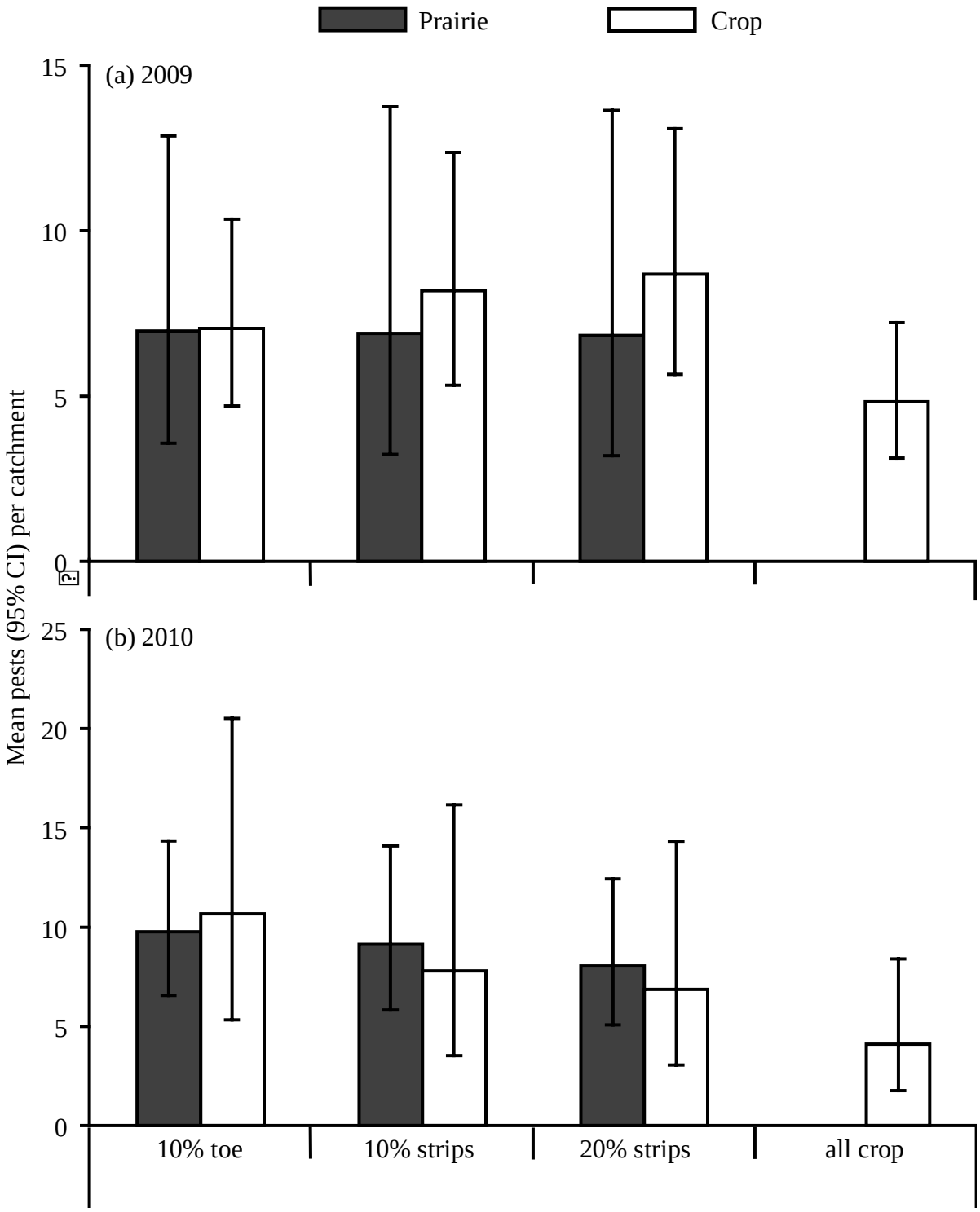
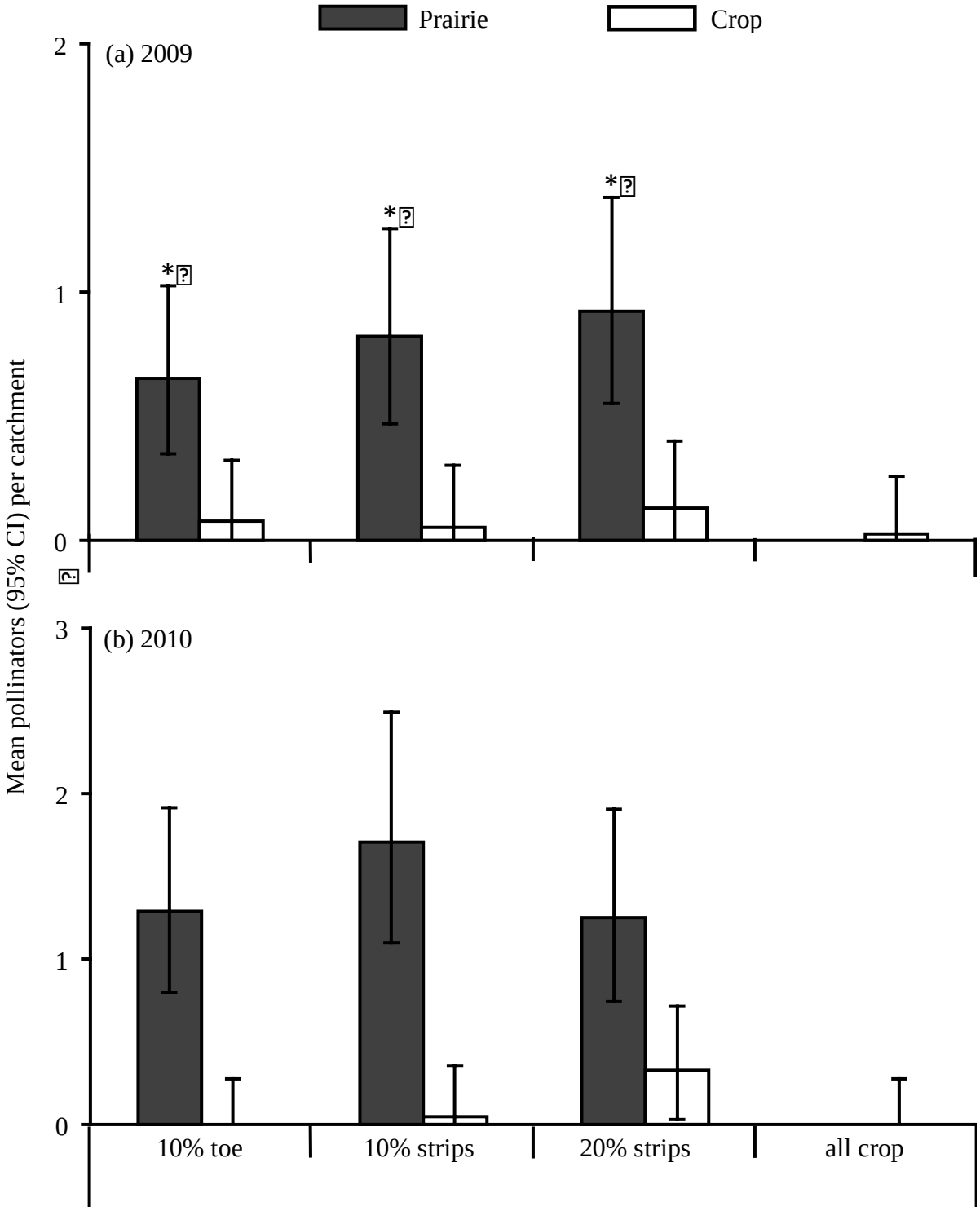

Prairie
Crop
(a) 2009
(b) 2010
Mean pests (95% CI) per catchment
0
5
10
15
20
25
10% toe
10% strips
20% strips
all crop

Figure 5.


Prairie
Crop
(a) 2009
(b) 2010
Mean pollinators (95% CI) per catchment
0
1
2
3
*?
10% toe
10% strips
20% strips
all crop

Chapter IV

General Conclusions

Chapter two:

- *Binodoxys communis* successfully colonized *Aphis glycines* within soybean fields in Iowa, and persisted for up to four generations in the field.
- Field releases of *B. communis* did not result in suppression of *A. glycines* populations.
- *Binodoxys communis* parasitism levels exhibited a directly density-dependent relationship with *A. glycines* densities at or below 300 aphids per plant, and an inverse-density dependent relationship to higher densities of aphids.

Chapter three:

- Nearly 60,000 arthropods were collected in 2009 and 2010, including natural enemies, pests, pollinators, and incidental arthropods. The abundance, species richness, and diversity of all guilds was greater within prairie land cover
- The natural enemy community at the NSNWR consisted of 10 orders, representing 60 families and over 156 species; the most abundant natural enemies were Araneae, while the most diverse natural enemy order were Hymenoptera.
- Land cover type had a significant impact on the abundance of natural enemies and pollinators, but not on pests.
- Of the eight most commonly collected natural enemy taxa in 2009, five were significantly more abundant within prairie (Araneae, Braconidae, Cantharidae, *Coenosia* spp., and Syrphidae); two taxa were significantly more abundant within

soybean (Coccinellidae and Nabidae); and one taxa was not collected more frequently from either land cover type (*Orius insidiosus*).

- Varying proportions and distributions of perennial plant coverage did not significantly affect the abundance and diversity of natural enemies, pests, or pollinators within the crop or prairie systems.

Acknowledgements

I would like to thank my family, for encouraging me, and putting up with my obsession to work on this thesis during holidays, birthdays, weekends, and into the dead of the night. Specifically, my parents Doug and Char, and sister Leah have given unwavering support, reminding me that the end is in sight. My husband Dave has been my biggest role model and coach. He certainly deserves an award for enduring the mess of my books and non-strop ramblings about unbalanced, non-normal, hierarchical experimental design analysis.

I would also like to thank my major professor, Dr. Matt O'Neal for being a great mentor. For such an animated and high-spirited man, he was stringent and relentless when it counted. He never let me settle for mediocrity, and reminded me that to be a jack-of-all-trades, you must be a master of none. My committee members Dr. Erin Hodgson and Dr. Diane Debinski also provided wonderful feedback, and I am grateful for their sincerity.

Of course, none of my research would be complete without the help of my fellow graduate students and undergraduate help. My fellow office-mate and friend Kelly Gill was a major component in my sanity. I can honestly say that I relished every moment of up-hill insect collecting retreats, and counting thousands of aphids per plant in the blistering heat. However, it goes without saying that without the help of countless undergraduate workers, I wouldn't have enjoyed it as much. Greg VanNostrand (now the lab supervisor), Shaylyn Wiarda, Renee Taphorn, Steve Longwell, Joe Weelock, Alyssa Hajek-Jones, Alyssa Bertelsen, Andy Pudenz, and of course Laura Helmich.

Appendix A

Table A1. Mean ± SE soybean aphids and mean parasitized aphids (*B. communis* mummies) per plant across treatments for each release site by count date in 2008 field release trials

Release site *Treatment* [a]	Wasp release Week 1 (7/16 - 7/23)[b]		Cage opening Week 3 (7/30 - 8/8)		Wasp spread Week 5 (8/12 - 8/19)		Whole field counts Week 7 (9/2 – 9/9)
	Aphids[c]	Mummies[d]	Aphids	Mummies	Aphids	Mummies	Mummies
Northern							
M	515 ± 113	(6.50)	5995 ± 622	(11.40)	NA		(1.04)
A	515 ± 50	(NA)	6123 ± 615	(NA)			
U	97 ± 35	(NA)	326 ± 46	(NA)			
Northwestern							
M	1029 ± 286	(5.44)	9303 ± 702	(89.06)	4920 ± 477	(41.19)	(1.84)
A	368 ± 27	(NA)	7814 ± 775	(NA)	2999 ± 595	(3.94)	
U	900 ± 87	(NA)	4808 ± 197	(NA)	4110 ± 413	(2.63)	
Southeastern							
M	591 ± 122	(5.13)	8050 ± 834	(14.13)	4081 ± 799	(60.88)	(2.59)
A	1283 ± 248	(NA)	8056 ± 1017	(NA)	4215 ± 840	(0.25)	
U	20 ± 7	(NA)	148 ± 27	(NA)	861 ± 212	(0.00)	
Southern							
M	4 ± 1	(5.00)	220 ± 80	(2.94)	318 ± 43	(2.31)	(0.00)
A	6 ± 3	(NA)	50 ± 10	(NA)	263 ± 28	(0.00)	
U	3 ± 1	(NA)	11 ± 3	(NA)	163 ± 21	(0.06)	

[a] Treatments: M, cage infested with aphids, and inoculated with *B. communis*; A, cage infested with aphids; U, un-caged infested with aphids. M, cage infested with aphids, and inoculated with *B. communis*; A, cage infested with aphids; U, un-caged infested with aphids.

[b] Aphids were counted bi-monthly on all four plants within each treatment plot; mummies were counted in M cages in week 1 and 3 counts, and counted in each treatment plot in week 5 and 7 counts; entire fields were scouted for aphids and mummies in week 7 counts. Initial field infestation of aphids occurred between 26 June - 2 July; Wasps were released into M cages on week 1; Cages were opened on week 3; aphids and mummies were counted in each treatment plot on week 7.

[c] Mean aphids ± standard errors per plant.

[d] Mean mummies per plant.

Table A2. Mean ± SE soybean aphids and mean parasitized aphids (*B. communis* mummies) per plant for each release site and count date per treatment in 2009 field release trials

Release site *Treatment* [a]	**Wasp release Week 1 (6/26 - 7/7)** [b]		**Cage opening Week 3 (7/8 - 7/22)**		**Wasp spread Week 5 (7/24 - 8/5)**		**Whole field counts Week 7 (8/6 – 8/19)**			
	Aphids [c]	Mummies [d]	Aphids	Mummies	Aphids	Mummies	Aphids	Mummies	Aphids	Mummies
Northern									**Entire field**	
M	290 ± 87	(12.50)	3072 ± 359	(36.56)	3502 ± 284	(180.31)	2225 ± 618	(82.56)	168 ± 13	(1)
A	522 ± 92	(NA)	5320 ± 610	(NA)	3747 ± 632	(8.75)	1985 ± 454	(20.69)		
U	7 ± 2	(NA)	49 ± 11	(NA)	694 ± 101	(4.88)	1421 ± 265	(28.81)		
Southern									**Entire field**	
M	244 ± 74	(5.00)	1441 ± 351	(1.10)	11430 ± 2157	(13.60)	3139 ± 674	(20.60)	198 ± 25	(0)
A	247 ± 99	(NA)	650 ± 145	(NA)	10525 ± 1879	(0.00)	2672 ± 671	(0.60)		
U	3 ± 2	(NA)	2.1 ± 1	(NA)	13 ± 2	(0.00)	98 ± 12	(0.10)		
Southeastern									**Entire field**	
M	5 ± 0	(12.50)	60 ± 20	(8.40)	939 ± 86	(4.75)	1673 ± 277	(1.75)	604 ± 104	(1)
A	5 ± 0	(NA)	32 ± 13	(NA)	1861 ± 514	(0.50)	3003 ± 477	(2.75)		
U	5 ± 0	(NA)	3 ± 1	(NA)	72 ± 23	(0.00)	566 ± 109	(0.00)		

[a] Treatments: M, cage infested with aphids, and inoculated with *B. communis*; A, cage infested with aphids; U, un-caged infested with aphids. M, cage infested with aphids, and inoculated with *B. communis*; A, cage infested with aphids; U, un-caged infested with aphids.

[b] Aphids were counted bi-monthly on all four plants within each treatment plot; mummies were counted in M cages in week 3 counts, and counted in each treatment plot in week 5 and 7 counts; entire fields were scouted for aphids and mummies in week 7 counts. Initial field infestation of aphids occurred between 26 June - 2 July; wasps were released into M cages on week 1; cages were opened on week 3; aphids and mummies were counted in each treatment plot on week 7.

[c] Mean aphids ± standard errors per plant.

[d] Mean mummies per plant.

Table A3. Mean ± SE soybean aphids and mean parasitized aphids (*B. communis* mummies) per plant for each release site and count date per treatment in 2010 field release trials

Research	**Wasp Release**		**Cage Opening**		**Wasp Spread**		**Final Field Counts**			
Treatment [a]	**Week 1 (7/8 – 7/21)** [b]		**Week 3 (7/23 – 8/1)**		**Week 5 (8/5 – 8/19)**		**Week 7 (8/16 – 8/19)**			
	Aphids [c]	Mummies [d]	Aphids	Mummies	Aphids	Mummies	Aphids	Mummies	Aphids	Mummies
Northwestern[e]									**Entire Field**	
M	108 ± 33	(5.00)	2739 ± 368	(5.75)	774 ± 72	(3.25)	389 ± 46	(0.19)	206 ± 17	(0.00)
A	1486 ± 147	(NA)	6005 ± 937	(0.00)	328 ± 43	(1.56)	59 ± 9	(0.00)		
U	63 ± 24	(NA)	391 ± 119	(2.73)	917 ± 151	(4.27)	468 ± 50	(0.80)		
Southern							**Entire Field**			
M	202 ± 90	(5.00)	718 ± 130	(2.13)	60 ± 11	(2.25)	2 ± 0	(0.00)		
A	47 ± 13	(NA)	489 ± 125	(NA)	55 ± 12	(0.00)				
U	5 ± 2	(NA)	9 ± 5	(NA)	14 ± 4	(0.00)				
Southeastern							**Entire Field**			
M	1381 ± 114	(5.00)	4096 ± 756	(6.63)	94 ± 14	(0.00)	13 ± 5	(0.00)		
A	2899 ± 244	(NA)	3431 ± 462	(NA)	311 ± 85	(2.44)				
U	27 ± 7	(NA)	34 ± 5	(NA)	87 ± 9	(0.00)				

[a] Treatments: M, cage infested with aphids, and inoculated with *B. communis*; A, cage infested with aphids; U, un-caged infested with aphids. M, cage infested with aphids, and inoculated with *B. communis*; A, cage infested with aphids; U, un-caged infested with aphids.

[b] Initial field releases of aphids occurred on the following dates for these research farms, Northwestern (6/9); Southern (6/28); and Southeastern (6/28).

[c] Mean aphids ± standard errors per plant.

[d] Mean mummies per plant.

[e] The Northwestern site was impacted by damaging weather events during the sixth week of the experiment.

Table A4. Mean ± SE soybean aphids and mean parasitized aphids (*B. communis* mummies) per plant for each release site and count date per treatment in 2009 aphid density study

Release site	Wasp release Week 1 (7/2 - 7/7) [a]		Cage open Week 3 (7/15 - 7/22)		Wasp spread Week 5 (7/28- 7/29)		Final field counts Week 7 (8/4 – 8/12)			
Treatment [b]	Aphids (A) [c]	Mummies (M) [d]	A	M	A	M	A	M	A	M
Northwestern									**Entire field**	
Hm	1738 ± 464	(12.50)	6123 ± 892	(1.43)	1304 ± 198	(1.33)	2405 ± 484	(0.21)	1821 ± 189	(1)
Lm	17 ± 7	(12.50)	131 ± 35	(7.95)	992 ± 319	(18.65)	2605 ± 460	(6.75)		
H	40 ± 0	(NA)	1081 ± 479	(NA)	511 ± 138	(1.80)	2663 ± 336	(0.00)		
L	NA ± NA	(NA)	35 ± 11	(NA)	29 ± 6	(1.40)	1181 ± 110	(0.00)		
Central									**Entire field**	
Hm	3499 ± 422	(12.50)	10867 ± 1649a	(25.35)	1000 ± 0	(16.15)	2559 ± 654	(36.20)	1841 ± 227	(1)
Lm	6 ± 1	(12.50)	5186 ± 1692b	(43.85)	680 ± 49	(111.85)	3299 ± 630	(132.05)		
H	50 ± 0	(NA)	1729 ± 403b	(NA)	820 ± 27	(0.00)	3311 ± 406	(1.00)		
L	NA		(NA)		69 ± 15	(NA)	540 ± 31	(0.00)	1536 ± 222	(0.16)

[a] Aphids were counted bi-monthly on all four plants within each treatment plot; mummies were counted in M cages in week 3 and 5 counts, and counted in each treatment plot in week 5 and 7 counts; entire fields were scouted for aphids and mummies in week 7 counts. Initial field infestation of aphids occurred between 10 June - 18 June; Wasps were released into M cages on week 1; Cages were opened on week 3; aphids and mummies were counted in each treatment plot on week 5 and 7.

[b] Treatments: Hm, cage infested with high densites of aphids, and inoculated with *B. communis* mummies; Lm, cage infested with low densities of aphids, and inoculated with *B. communis* mummies; H, cage infested with high densities of aphids; L, cage infested with low densites of aphids.

[c] Mean aphids per plant ± standard errors.

[d] Mean mummies per plant.

Table A5. Mean ± SE soybean aphids and mean parasitized aphids (*B. communis* mummies) per plant for each release site and count date per treatment in 2010 aphid density study

Release site	Wasp release Week 1 (7/16 - 7/20) [a]		Cage open Week 3 (7/26 – 8/3)		Wasp spread Week 5 (8/6 – 8/10)		Destructive counts Week 7 (8/10 – 8/13)			
Treatment [b]	Aphids (A) [c]	Mummies (M) [d]	A	M	A	M	A	M	A	M
Northern							**Entire Field**			
Hm	3867 ± 333	(10.00)	907 ± 167	(4.20)	490 ± 100	(0.65)	44 ± 3	(0.00)		
Lm	24 ± 4	(10.00)	1347 ± 129	(4.16)	783 ± 63	(2.79)				
H	2441 ± 315	(NA)	1128 ± 111	(1.40)	619 ± 75	(0.00)				
L	20 ± 4	(NA)	686 ± 186	(NA)	269 ± 47	(0.00)				
Central									**Entire Field**	
Hm	4326 ± 416	(12.50)	1499 ± 371	(29.40)	282 ± 29	(0.75)	133 ± 19	(0.00)	18 ± 1	(0.01)
Lm	18 ± 2	(12.50)	383 ± 54	(2.40)	245 ± 22	(1.15)	133 ± 24	(0.05)		
H	2727 ± 459	(NA)	786 ± 54	(NA)	179 ± 27	(0.00)	110 ± 21	(0.00)		
L	73 ± 10	(NA)	736 ± 126	(NA)	171 ± 22	(0.00)	75 ± 10	(0.00)		

[a] Aphids were counted bi-monthly on all four plants within each treatment plot; mummies were counted in M cages in week 3 and 5 counts, and counted in each treatment plot in week 5 and 7 counts; entire fields were scouted for aphids and mummies in week 7 counts. Initial field infestation of aphids occurred between 15 June - 16 June; Wasps were released into M cages on week 1; Cages were opened on week 3; aphids and mummies were counted in each treatment plot on week 5 and 7.

[b] Treatments: Hm, cage infested with high densites of aphids, and inoculated with *B. communis* mummies; Lm, cage infested with low densities of aphids, and inoculated with *B. communis* mummies; H, cage infested with high densities of aphids; L, cage infested with low densites of aphids.

[c] Mean aphids per plant ± standard errors.

[d] Mean mummies per plant.

Appendix B

Table B1. Natural enemies sampled in prairie and soybean in 2009 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon[a]	Prairie[b]	Soybean	Sum
ARANEAE	1497	189	1686
OPILIONES	57	30	87
COLEOPTERA			
Harmonia axyridis (Pallas)	245	798	1043
Chauliognathus pensylvanicus (DeGeer)	428	5	433
Cycloneda munda (Say)	31	47	74
Chauliognathus marginatus (Fabricius)	50	3	53
Hippodamia convergens Guérin-Méneville	9	21	30
Coccinellidae unknown[c]	1	26	27
Cantharidae unknown	25	1	26
Coleomegilla maculata (DeGeer)	9	9	18
Staphylinidae[d]	14	4	18
Hippodamia parenthesis (Say)	9	1	10
Carabidae unknown	6	0	6
Coccinella septempunctata (Linnaeus)	4	0	4
Collops spp.	1	1	2
Lebia viridis (Say)	2	0	2
Ditemnus spp.	1	0	1
Lampyridae	0	1	1
Melyridae unknown	1	0	1
DIPTERA			
Toxomerus marginatus (Say)	512	15	527
Coenosia spp.	197	21	218
Dolichopodidae	134	65	199
Toxomerus politus (Say)	72	16	88
Syrphidae unknown	79	5	84
Tachinidae	49	10	59
Toxomerus geminatus (Say)	41	4	45
Empididae	13	3	16
Chamaemyiidae	11	2	13
Melanostoma scalare (Fabricius)	12	0	12
Sphaerophoria spp.	12	0	12
Epistrophe spp.	2	3	5
Helophilus fasciatus Walker	5	0	5
Othonevra nitida (Wiedemann)	5	0	5
Asilidae	5	0	5
Aphidoletes aphidimyza (Rondani)	4	0	4
Rhagionidae	3	1	4
Sciomyzidae	4	0	4
Eristalis spp.	3	0	3
Platycheirus spp.	2	1	3
Syritta pipiens (Linnaeus)	3	0	3
Micropezidae	3	0	3
Bombyliidae	2	0	2

Table B1. continued

Taxon[a]	Prairie[b]	Soybean	Sum
DIPTERA			
Melanostoma mellinum (Linnaeus)	2	0	2
Therevidae	2	0	2
Toxomerus occidentalis Curran	1	0	1
Allograpta obliqua (Say)	1	0	1
Paragus spp.	1	0	1
HEMIPTERA			
Orius insidiosus (Say)	960	394	1354
Nabis spp.	135	188	323
Podisus maculiventris (Say)	57	49	106
Sinea diadema Fabricius	28	1	29
Reduviidae unkown	24	1	25
Zelia spp.	18	0	18
Berytidae	14	2	16
Phymata spp.	5	0	5
Geocoridae	3	1	4
Nabicula spp.	2	1	3
HYMENOPTERA			
Eulophidae	128	34	162
Ichneumonidae	128	21	149
Pteromalidae	119	9	128
Braconidae unknown	90	15	105
Braconidae A082[e]	91	2	93
Cotesia spp.	76	7	83
Aphidiinae	45	5	50
Neralsia spp.	40	2	42
Eucoilinae	32	0	32
Eurytomidae A104	31	0	31
Figitidae A057	21	0	21
Parasitoid unknown	14	6	20
Scelionidae	17	2	19
Proctotrupidae	17	0	17
Tiphiidae	16	0	16
Torymidae	16	0	16
Eurytomidae A081	14	0	14
Eupelmidae	12	1	13
Microplitis spp.	11	2	13
Alysiinae	9	3	12
Eurytomidae A061	9	0	9
Eurytomidae unknown	9	1	10
Eurytoma spp.	11	0	11
Braconidae A092	9	0	9
Chelioninae	9	0	9

Table B1. continued

Taxon[a]	Prairie[b]	Soybean	Sum
HYMENOPTERA			
Encyrtidae	7	1	8
Eurytomidae 104	7	1	8
Parasitoid 103	7	0	7
Chalcididae	6	0	6
Eurytomidae A052	5	1	6
Tetramesa elongata (Riley)	6	0	6
Agathidinae	5	0	5
Eulophidae 116	1	4	5
Ormyridae	5	0	5
Pompilidae	5	0	5
Rogadinae	5	0	5
Vespidae	4	1	5
Braconidae A084	4	0	4
Eurytomidae A038	4	0	4
Eurytomidae A056	4	0	4
Parasitoid 104	2	1	3
Braconidae A091	3	0	3
Brachistini	3	0	3
Eulophid A054	3	0	3
Evaniidae	3	0	3
Figitinae	3	0	3
Platygastridae	3	0	3
Parasitoid 105	1	1	2
Parasitoid 113	1	1	2
Eulophidae 114	0	2	2
Parasitoid 116	2	0	2
Anacharis spp.	1	1	2
Ceraphronidae	2	0	2
Crabronidae	2	0	2
Diapriidae	2	0	2
Euphorinae	1	1	2
Eurytomidae A053	2	0	2
Eurytomidae A058	2	0	2
Eurytomidae A072	2	0	2
Parasitoid 101	0	1	1
Parasitoid 106	1	0	1
Parasitoid 107	1	0	1
Parasitoid 111	1	0	1
Parasitoid 115	0	1	1
Parasitoid 117	1	0	1
Parasitoid 118	1	0	1

Table B1. continued

Taxon[a]	Prairie[b]	Soybean	Sum
HYMENOPTERA			
Parasitoid A047	1	0	1
Braconidae A083	1	0	1
Braconidae A087	1	0	1
Braconidae A090	1	0	1
Aphidiinae A093	1	0	1
Braconidae A097	1	0	1
Alysson sp.	1	0	1
Aphelinidae	0	1	1
Asaphes spp.	1	0	1
Bethylidae	1	0	1
Chrysididae	1	0	1
Cynipoid A067	0	1	1
Eurytomidae A068	1	0	1
Eurytomidae A076	1	0	1
Figitinae A063	1	0	1
Gasteruptiidae	1	0	1
Megaspilidae	1	0	1
Parasitoid A086	1	0	1
Perilampidae	1	0	1
Sphecidae	1	0	1
MECOPTERA			
Panorpa spp.	3	0	3
NEUROPTERA			
Chrysoperla spp.	80	51	131
Hemerobius spp.	10	56	66
ODONATA			
Coenagrionidae	5	2	7
Grand total	6024	2157	8181
Species richness (S)	141[e]	66	147
Shannon's diversity index (H′)[f]	3.06	2.31	
Evenness (E)	0.62	0.55	
Percent similarity (S_{ij})			44.02%

[a] Seasonal abundance of natural enemies calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of soybean and summed across all sampling dates (once per month May through September in prairie; once per month June through September within soybean) in 2009.

Table B1. continued

[b] Prairie and soybean samples taken within the STRIPs research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPs = Science-based Trials of Rowcrops Integrated with Prairies.

[c] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[d] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for entire arthropod community, and morphospecies were not logged for the taxon.

[e] Taxa accompanied by number and letter code are undetermined morphospecies.

[f] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B2. Natural enemies sampled in prairie and corn in 2010 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon[a]	Prairie[b]	Corn	Sum
ARANEAE	2606	50	2656
OPILIONES	189	1	190
COLEOPTERA			
Chauliognathus pensylvanicus (DeGeer)	273	0	273
Coleomegilla maculata (DeGeer)	102	44	146
Cycloneda munda (Say)	62	1	63
Ditemnus spp.	27	0	27
Cantharidae unknown[c]	24	0	24
Chauliognathus marginatus (Fabricius)	25	0	25
Staphylinidae[d]	20	1	21
Carabidae unknown	14	0	14
Isohydnocera tabida (LeConte)	8	0	8
Harmonia axyridis (Pallas)	4	1	5
Hyperaspis undulata (Say)	3	0	3
Lebia viridis (Say)	3	0	3
Collops tricolor (Say)	3	0	3
Coccinellidae unknown	2	1	3
Coccinella septempunctata (L.)	2	0	2
Trypherus latipennis (Germar)	2	0	2
Cicindellidae	2	0	2
Ellychnia spp.	2	0	2
Lucidota atra (Olivier)	1	1	2
Cycloneda polita Casey	1	0	1
Hippodamia convergens Guérin-Méneville	1	0	1
Hippodamia parenthesis (Say)	1	0	1
Photinus pyralis (Linnaeus)	1	0	1
Enoclerus rosmarus (Say)	1	0	1
Collops spp.	1	0	1
Collops pallipes Marshall	1	0	1
DIPTERA			
Dolichopodidae	279	15	294
Toxomerus marginatus (Say)	206	1	207
Coenosia spp.	183	3	186
Empididae	58	3	61
Chamaemyiidae	52	0	52
Tachinidae	45	0	45
Sciomyzidae	39	0	39
Othonevra nitida (Wiedemann)	34	0	34
Syrphidae unknown	30	0	30
Eristalis spp.	22	0	22
Asilidae	21	0	21
Melanostoma scalare (Fabricius)	20	0	20
Toxomerus politus (Say)	17	0	17
Aphidoletes aphidimyza (Rondani)	10	7	17

Table B2. continued

Taxon[a]	Prairie[b]	Corn	Sum
DIPTERA			
Platycheirus scambus (Staeger)	15	0	15
Toxomerus geminatus (Say)	15	0	15
Helophilus fasciatus Walker	14	0	14
Sphaerophoria spp.	11	0	11
Allograpta obliqua (Say)	7	0	7
Conopidae	7	0	7
Epistrophe spp.	4	0	4
Paragus spp.	4	0	4
Syritta pipiens (Linnaeus)	4	0	4
Micropezidae	4	0	4
Rhagionidae	2	0	2
Melanostoma mellinum (Linnaeus)	1	0	1
Palapada vinetorum (Fabricius)	1	0	1
Cheilosia spp.	1	0	1
HEMIPTERA			
Orius insidiosus (Say)	299	16	315
Berytidae	297	2	299
Podisus maculiventris (Say)	115	0	115
Nabis spp.	53	1	54
Sinea diadema (Fabricius)	31	0	31
Reduviidae unkown	29	0	29
Nabicula spp.	13	0	13
Phymata spp.	9	0	9
HYMENOPTERA			
Eulophidae unknown	367	7	374
Braconidae unknown	162	6	168
Pteromalidae unknown	154	3	157
Cotesia spp.	128	0	128
Parasitoid unknown	65	2	67
Eurytomidae unknown	65	1	66
Ichneumonidae unknown	64	0	64
Tetramesa elongata	55	0	55
Encyrtidae	31	1	32
Eucoilinae	25	6	31
Eurytoma spp.	30	0	30
Neralsia spine	29	0	29
Polistes spp.	26	0	26
Eupelmidae	16	6	22
Torymidae	21	1	22
Scelionidae	19	3	22
Eurytomidae A061[e]	20	0	20
Eurytomidae A052	19	0	19
Ceraphronidae	4	14	18
Eurytomidae A053	16	0	16
Ormyridae	16	0	16

Table B2. continued

Taxon[a]	Prairie[b]	Corn	Sum
HYMENOPTERA			
Platygastridae	15	1	16
Microplitis	15	0	15
Brachistini	14	0	14
Chalcididae	11	0	11
Figitinae	11	0	11
Braconidae A082[e]	10	0	10
Eurytomidae A081	10	0	10
Chelioninae	9	0	9
Aphidiine	8	0	8
Alysiinae	6	1	7
Eurytomidae A068	7	0	7
Tiphiidae	7	0	7
Agathidinae	6	0	6
Braconinae	6	0	6
Mymaridae	2	4	6
Perilampidae A105	6	0	6
Megaspilidae	4	2	6
Eurytomidae A056	5	0	5
Eurytomidae 104	4	0	4
Bethylidae	4	0	4
Pompilidae	4	0	4
Gelis spp.	3	0	3
Eurytomidae A038	3	0	3
Eurytomidae A058	3	0	3
Eurytomidae A070	3	0	3
Diapriidae	2	1	3
Alysson sp.	3	0	3
Exochus semirufus	2	0	2
Braconidae A091	2	0	2
Euphorinae	2	0	2
Rogadinae	2	0	2
Bracon cf-intercessor	2	0	2
Eurytomidae A072	2	0	2
Perilampidae	2	0	2
Gyron sp.	2	0	2
Crabronidae unknown	2	0	2
Aptesis spp.	1	0	1
Braconidae A042	1	0	1
Figitidae A057	1	0	1
Proctotrupidae	1	0	1
Eurytomidae A081	1	0	1
Eurytoma	1	0	1
Braconidae A092	1	0	1
Braconidae A097	1	0	1
Braconidae A0100	1	0	1
Habracon spp.	1	0	1
Aphelinidae	1	0	1

Table B2. continued

Taxon[a]	Prairie[b]	Corn	Sum
HYMENOPTERA [f]			
Eulophid A054	1	0	1
Eurytomidae A039	1	0	1
Eurytomidae A047	1	0	1
Eurytomidae A060	1	0	1
Eurytomidae A080	1	0	1
Cerceris kenicotti	1	0	1
Sphecidae	1	0	1
Chrysididae	1	0	1
Dryinidae	1	0	1
Vespidae	1	0	1
MECOPTERA			
Panorpa spp.	6	0	6
NEUROPTERA			
Chrysoperla spp.	140	5	145
Hemerobius spp.	4	1	5
ODONATA			
Coenagrionidae	12	0	12
Lestidae	1	0	1
Grand total	7048	213	7248
Species richness (S)	147[e]	34	145
Shannon's diversity index (H′)[f]	3.03	2.66	
Evenness (E)	0.61	0.76	
Percent similarity (S_{ij})			12.06%

[a] Seasonal abundance of natural enemies calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of corn and summed across all sampling dates (once per month May through September in prairie; once per month June through August in corn) in 2010.

[b] Prairie and soybean samples taken within the STRIPs research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPs = Science-based Trials of Rowcrops Integrated with Prairies.

[c] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens

[d] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for the entire arthropod community, and morphospecies were not logged for the taxon.

[e] Taxa accompanied by number and letter code are undetermined morphospecies.

[f] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B3. Pest arthropods sampled in prairie and soybean in 2009 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon [a]	Prairie [b]	Soybean	Sum
COLEOPTERA			
Diabrotica undecimpunctata Mannerheim	75	16	91
Calomycterus setarius Roelofs	32	37	69
Cerotoma trifurcata Förster	1	13	14
Colaspis brunnea Fabricius	2	9	11
Meloidae	2	2	4
DIPTERA			
Rivellia spp.	131	60	191
HEMIPTERA			
Lygus spp. nymph	2055	122	2177
Lygus spp.	1985	96	2081
Halticus bractatus Say	732	573	1305
Aphididae	511	86	597
Empoasca fabae Harris	263	111	374
Pentatomidae nymph	141	94	235
Aphididae alatae	37	52	89
Acrosternum hilare (Say)	14	15	29
Euschistus servus (Say)	26	3	29
Pentatomidae unknown [c]	3	2	5
Spissistilus festinus Say	1	0	1
LEPIDOPTERA			
Lepidoptera larvae unkown	57	66	123
Pyrrharctia isabella (Smith)	77	0	77
Inchworm [d]	8	2	10
Helicoverpa zea (Boddie)	7	0	7
Hypena scabra (Fabricius)	5	0	5
Agrotis ipsilon (Hufnagel)	4	0	4
Anticarsia gemmatalis Hübner	0	1	1
Colias eurytheme (Boisduval)	1	0	1
Pseudoplusia includens (Walker)	1	0	1
ORTHOPTERA			
Cyrtacanthacridinae	70	10	80
Melanoplus femurrubrum De Geer	41	7	48
Melanoplus differentialis Thomas	33	1	34
Melanoplus sanguinipes Fabricius	6	2	8
Melanoplus bivittatus Say	27	6	33

Table B3. continued

Taxon [a]	Prairie [b]	Soybean	Sum
THYSANOPTERA	4	0	4
Grand total	6352	1386	7738
Species richness (S)	32	24	33
Shannon's diversity index (H′)[e]	2.64	1.49	
Evenness (E)	0.76	0.47	
Percent similarity (S_{ij})			44.17%

[a] Seasonal abundance of economically important soybean pests calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of soybean and summed across all sampling dates (once per month May through September in prairie; once per month June through September within soybean) in 2009.

[b] Prairie and soybean samples taken within STRIPS research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPS= Science-based Trials of Rowcrops Integrated with Prairies.

[c] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[d] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for entire arthropod community, and morphospecies were not logged for the taxon.

[e] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B4. Pests sampled in prairie and corn in 2010 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon [a]	Prairie [b]	Corn	Sum
COLEOPTERA			
Diabrotica undecimpunctata Mannerheim	290	5	295
Diabrotica barberi Smith; Lawrence	218	5	223
Chaetocnema pulicaria Melsheimer	139	0	139
Stenolophus C016 [c]	18	51	69
Nitidulidae [d]	53	1	54
Curculionidae C060	27	0	27
Elateridae	3	0	3
Stenolophus C045	2	0	2
HEMIPTERA			
Aphididae	370	2	372
Pentatomidae unknown nymph [e]	214	2	216
Aphididae alate	82	1	83
Euschistus servus (Say)	68	0	68
Acrosternum hilare (Say)	5	0	5
Blissus spp.	2	0	2
LEPIDOPTERA			
Lepidoptera larvae unknown	194	0	194
Cyrtacanthacridinae	351	1	352
ORTHOPTERA			
Melanoplus femurrubrum De Geer	28	0	28
Melanoplus differentialis Thomas	16	0	16
Melanoplus bivittatus Say	5	0	5
THYSANOPTERA	11	1	12
Grand total	2096	69	2165
Species richness (S)	20	9	20
Shannon's diversity index (H′) [f]	2.35	0.01	
Evenness (E)	0.78	0.01	
Percent similarity (S_{ij})			5.36%

[a] Seasonal abundance of economically important corn pests calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of corn and summed across all sampling dates (once per month May through September in prairie; once per month June through August within corn) in 2010.

[b] Prairie and corn samples taken within STRIPs research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPs = Science-based Trials of Rowcrops Integrated with Prairies.

Table B4. continued

[c] Taxa accompanied by number and letter code are undetermined morphospecies.

[d] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for entire arthropod community, and morphospecies were not logged for the taxon.

[e] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[f] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B5. Incidental arthropods sampled in prairie and soybean in 2009 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon [a]	Prairie [b]	Soybean	Sum
ACARI	11	2	13
COLEOPTERA			
Diabrotica barberi Smith; Lawrence	655	32	687
Epitrix spp.	238	16	254
Chaetocnema pulicaria Melsheimer	179	8	187
Alticini C028 [c]	51	1	52
Systena frontalis (Förster)	44	6	50
Cryptophagidae [d]	35	4	39
Systena hudsonias (Förster)	33	0	33
Carabidae C016	21	10	31
Chaetocnema spp.	28	3	31
Alticini C042	23	2	25
Alticini C020	20	0	20
Curculionidae C004	14	1	15
Nitidulidae	12	3	15
Curculionidae C010	14	0	14
Curculionidae C023	13	0	13
Mordellidae	10	3	13
Lixus spp.	11	1	12
Cassidini	10	0	10
Curculionidae unknown [e]	8	0	8
Anthicidae	1	6	7
Ceutorhynchini	6	0	6
Curculionidae C038	6	0	6
Coleoptera C007	4	0	4
Coleoptera immature	1	3	4
Curculionidae C010.5	3	0	3
Curculionidae C026	3	0	3
Leptinotarsa peninsularis Horn	3	0	3
Phyllotreta zimmermanni (Crotch)	1	2	3
Carabidae C008	2	0	2
Coleoptera unknown	1	1	2
Curculionidae C005	1	1	2
Curculionidae C017	2	0	2
Curculionidae C044	2	0	2
Elateridae	2	0	2
Languridae	2	0	2
Acalymma vittatum (Fabricius)	1	0	1
Alticini C045	0	1	1

Table B5. continued

Taxon [a]	Prairie [b]	Soybean	Sum
COLEOPTERA			
Alticini unknown	0	1	1
Chrysomelidae C019	1	0	1
Coleoptera C034	1	0	1
Cryptocephalinae	0	1	1
Curculionidae C001	1	0	1
Curculionidae C003	1	0	1
Dibolia borealis Chevrolat	0	1	1
Lupraea picta (Say)	1	0	1
Scarabaeidae	0	1	1
COLLEMBOLA	3	7	10
DIPLOPODA	1	0	1
DIPTERA			
Diptera unknown (minute flies)	1468	363	1831
Sciaridae	783	101	884
Anthomyiidae	225	35	260
Chloropidae	188	54	242
Pollenia spp.	130	19	149
Sphaeroceridae	34	27	61
Limoniidae	36	19	55
Tephritidae	38	5	43
Sepsidae	29	10	39
Phoridae	30	5	35
Mycetophilidae	15	18	33
Sarcophagidae	25	6	31
Musca autumnalis De Geer	24	4	28
Lucilia spp.	21	5	26
Tipulidae	14	10	24
Muscidae	20	3	23
Stratiomyidae	13	2	15
Culicidae	10	2	12
Muscoidea unknown	10	0	10
Chironomidae	4	5	9
Ceratopogonidae	3	5	8
Delphinia spp.	4	4	8
Chaetopsis spp.	6	1	7
Diptera larvae unknown	6	0	6
Fucellia rufitibia Stein	0	6	6

Table B5. continued

Taxon [a]	Prairie [b]	Soybean	Sum
DIPTERA			
Calliphoridae	5	0	5
Diptera unknown	5	0	5
Drosophildae D004	2	3	5
Lonchopteridae	2	1	3
Penthetria heteroptera (Say)	2	0	2
Diptera D013	1	0	1
Diptera D014	1	0	1
Diptera D016	1	0	1
Ephydridae	1	0	1
Tabanidae	0	1	1
EPHEMEROPTERA	1	4	5
HEMIPTERA			
Cicadellidae	821	107	928
Trigonotylus spp.	643	2	645
Cercopidae	211	5	216
Orthops spp.	183	6	189
Thyreocoridae	153	9	162
Adelphocoris lineolatus (Goeze)	154	7	161
Micrutalis calva (Say)	110	7	117
Mirid nymph	104	11	115
Adelphocoris rapidus Say	84	29	113
Bruchomorpha spp.	96	0	96
Alydidae	70	20	90
Delphacidae	80	5	85
Nysius spp.	53	0	53
Miridae unkown	35	3	38
Psyllidae	32	3	35
Lygaeidae unknown	31	3	34
Pachygronthidae	28	0	28
Tingidae nymph	27	0	27
Metriorrhynchomiris dislocatus (Say)	17	0	17
Holcostethus limbolarius (Stål)	15	0	15
Miridae unknown	13	0	13
Hemiptera unknown	7	1	8
Blissus spp.	6	0	6
Miridae H019	6	0	6
parasitized aphididae	5	1	6
Neottiglossa undata (Say)	5	0	5

Table B5. continued

Taxon [a]	Prairie [b]	Soybean	Sum
HEMIPTERA			
Derbidae	1	2	3
Lygaeus sp.	2	1	3
Miridae H007	2	0	2
Rhopalidae	2	0	2
Tingidae	1	1	2
Acanaloniidae	1	0	1
Campylenchia latipes (Say)	1	0	1
Cydnidae	1	0	1
Deraeocoris ruber Linnaeus	1	0	1
Dictyopharidae	1	0	1
Miridae H016	1	0	1
Neurocolpus nubilus (Say)	1	0	1
Piesmatidae	1	0	1
Salda sp.	1	0	1
Scutelleridae	1	0	1
HYMENOPTERA			
Formicidae	238	67	305
Symphyta larvae unknown	4	1	5
Tenthredinidae	1	0	1
LEPIDOPTERA			
Gelechioidea	37	43	80
Moth	24	13	37
Lycaenidae	7	0	7
Coleophoridae	1	0	1
Parasitized caterpillar	0	1	1
Pyraloidea	1	0	1
Unknown caterpillar	1	0	1
ORTHOPTERA			
Conocephalinae	59	0	59
Conocephalini	22	3	25
Copiphorini	9	0	9
Gomphocerinae	7	0	7
Tridactylidae	0	1	1
Oecanthinae	41	8	49
Oedipodinae	39	9	48
Phaneropterinae	3	0	3
Tetrigidae	3	0	3

Table B5. continued

Taxon [a]	Prairie [b]	Soybean	Sum
ORTHOPTERA			
Nemobiinae	79	0	79
PSOCOPTERA	1	6	7
INSECTA UNKNOWN	0	1	1
Grand total	8221	1211	9432
Species richness (S)	138	82	148
Shannon's diversity index (H′)[f]	3.33	3.07	
Evenness (E)	0.68	0.70	
Percent similarity (S_{ij})			38.22%

[a] Seasonal abundance of incidental arthropods (not economically important pests of soybean) calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of soybean and summed across all sampling dates (once per month May through September in prairie; once per month June through September within soybean) in 2009.

[b] Prairie and soybean samples taken within STRIPS research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPS= Science-based Trials of Rowcrops Integrated with Prairies.

[c] Taxa accompanied by number and letter code are undetermined morphospecies.

[d] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for entire arthropod community, and morphospecies were not logged for the taxon.

[e] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[f] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B6. Incidental arthropods sampled in prairie and corn in 2010 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon [a]	Prairie [b]	Corn	Sum
ACARI	22	1	23
COLEOPTERA			
Curculionidae C002 [c]	394	0	394
Corylophidae [d]	157	24	181
Curculionidae C023	136	0	136
Mordellidae	57	1	58
Systena hudsonias (Förster)	54	0	54
Curculionidae C005	48	0	48
Calomycterus setarius Roelofs	43	0	43
Curculionidae C046	27	0	27
Alticini C020	24	0	24
Curculionidae C038	22	0	22
Phyllotreta zimmermanni (Crotch)	19	2	21
Zonitis vittigera (LeConte)	20	0	20
Coleoptera larvae unknown [e]	17	0	17
Epicauta pennsylvanica De Geer	15	0	15
Cassidini	14	0	14
Curculionidae C010.5	14	0	14
Anthicidae	12	1	13
Systena frontalis (Förster)	11	0	11
Coleoptera C072	1	6	7
Curculionidae C004	7	0	7
Cerotoma trifurcata Förster	6	0	6
Lixus spp.	6	0	6
Coleoptera C068	5	0	5
Curculionidae C003	5	0	5
Labidomera clivicollis Kirby	5	0	5
Chaetocnema spp.	3	1	4
Coleoptera C055	4	0	4
Curculionidae C001	4	0	4
Curculionidae C010	4	0	4
Curculionidae C026	4	0	4
Curculionidae C044	4	0	4
Alticini C028	3	0	3
Coleoptera C006	3	0	3
Coleoptera C071	2	1	3
Curculionidae C059	3	0	3
Alticini C047	2	0	2
Ceutorhynchini	2	0	2

Table B6. continued

Taxon [a]	Prairie [b]	Corn	Sum
COLEOPTERA			
Ceutorhynchini	2	0	2
Chrysomelidae C067	2	0	2
Coleoptera C063	2	0	2
Coleoptera unknown	2	0	2
Cophes obtentus (Herbst)	2	0	2
Curculionidae C018	2	0	2
Hypera nigrirostris Fabricius	2	0	2
Languriini	2	0	2
Altica spp.	1	0	1
Alticini C042	1	0	1
Alticini C049	1	0	1
Alticini C052	1	0	1
Bruchidae	1	0	1
Buprestidae	1	0	1
Carabidae C008	1	0	1
Chrysochus auratus (Fabricius)	1	0	1
Chrysomelidae C056	1	0	1
Chrysomelidae unknown	1	0	1
Coleoptera C007	1	0	1
Coleoptera C009	1	0	1
Coleoptera C050	1	0	1
Coleoptera C062	1	0	1
Coleoptera C064	1	0	1
Coleoptera C066	1	0	1
Coleoptera C069	1	0	1
Coleoptera C070	1	0	1
Coleoptera C073	1	0	1
Coleoptera C074	1	0	1
Coleoptera C075	1	0	1
Coleoptera C076	1	0	1
Coleoptera C077	1	0	1
Coleoptera C079	1	0	1
Coleoptera C080	1	0	1
Cryptocephalinae	1	0	1
Curculionidae C012	1	0	1
Curculionidae C017	1	0	1
Curculionidae C021	1	0	1
Curculionidae C035	1	0	1
Leptinotarsa peninsularis Horn	1	0	1
Zygogramma suturalis (Fabricius)	1	0	1

Table B6. continued

Taxon [a]	Prairie [b]	Corn	Sum
COLEOPTERA			
Chrysomelidae C019	0	0	0
Coleoptera C034	0	0	0
COLLEMBOLA	2	4	6
DIPLOPODA	2	0	2
DIPTERA			
Diptera unknown (minute)	4218	202	4420
Chloropidae	234	6	240
Bibionomorpha	0	225	225
Rivellia spp.	120	18	138
Chironomidae	83	54	137
Chaetopsis spp.	110	2	112
Cecidomyiidae	77	20	97
Anthomyiidae	82	1	83
Limoniidae	83	0	83
Sarcophagidae	69	0	69
Sepsidae	65	0	65
Tipulidae	51	0	51
Scatopsidae	25	16	41
Sciaridae	35	5	40
Culicidae	31	4	35
Trupanea vicina (Wulp)	33	0	33
Muscidae	30	1	31
Dioxyna spp.	24	0	24
Mycetophilidae	16	8	24
Drosophilidae D004	18	3	21
Pollenia spp.	21	0	21
Sphaeroceridae	20	1	21
Musca autumnalis De Geer	18	0	18
Stratiomyidae	16	0	16
Phoridae	6	2	8
Lucilia spp.	5	1	6
Paracantha gentilis Hering	6	0	6
Simuliidae	2	4	6
Delphinia spp.	4	0	4
Lonchopteridae	2	2	4
Diptera unknown	3	0	3
Fannidae	0	2	2

Table B6. continued

Taxon [a]	Prairie [b]	Corn	Sum
DIPTERA			
Tabanidae	2	0	2
Curranops spp.	1	0	1
Ephydridae	0	1	1
Eurosta solidaginis (Fitch)	1	0	1
Homalocephala spp.	1	0	1
Icterica seriata (Loew)	1	0	1
Tephritis spp.	1	0	1
Tomoplagia obliqua (Say)	1	0	1
Diptera larvae unknown	0	0	0
EPHEMEROPTERA	0	1	1
HEMIPTERA			
Adelphocoris lineolatus (Goeze)	2662	0	2662
Lygus spp.	1950	22	1972
Lygus spp. nymph	1772	3	1775
Cicadellidae	1634	22	1656
Cercopidae	947	2	949
Empoasca fabae Harris	567	164	731
Trigonotylus spp.	446	1	447
Psyllidae	350	1	351
Thyreocoridae	310	0	310
Lygaeidae	248	0	248
Neortholomus scolopax (Say)	191	0	191
Micrutalis spp.	179	4	183
Cymus spp.	165	0	165
Adelphocoris rapidus Say	149	0	149
Delphacidae	119	5	124
Bruchomorpha spp.	85	2	87
Orthops spp.	79	0	79
Halticus bractatus Say	65	11	76
Oncopeltus fasciatus Dallas	67	0	67
Alydidae	53	0	53
Lygaeidae nymph	45	0	45
Metriorrhynchomiris dislocatus (Say)	42	0	42
Dictyopharidae	38	0	38
Lygaeus kalmii Stål	33	0	33
Miridae nymph	25	0	25
Nysius spp.	24	0	24
Holcostethus limbolarius (Stål)	18	0	18

Table B6. continued

Taxon [a]	Prairie [b]	Corn	Sum
HEMIPTERA			
Rhyparochromidae H014	18	0	18
Miridae H034	11	5	16
Spissistilus festinus Say	14	0	14
Tingidae nymph	14	0	14
Derbidae	3	10	13
Rhyparochromatidae nymph	13	0	13
Miridae H038	11	0	11
Neurcrolpus nubilis (Say)	9	1	10
Coreidae	8	0	8
Hemiptera unknown	7	0	7
Cosmopepla lintneriana Kirkaldy	6	0	6
Pentatomidae unknown	5	0	5
Piesmatidae	5	0	5
Acanaloniidae	4	0	4
Harmostes H024	4	0	4
Hemiptera H039	2	0	2
Mormidea lugens (Fabricius)	2	0	2
Neottiglossa undata (Say)	2	0	2
Rhopalidae	2	0	2
Clastoptera proteus Fitch	1	0	1
Ectopiocerus anthracinus Uhler	1	0	1
Entylia carinata Forster	1	0	1
Harmostes H017	1	0	1
Melanorhopala clavata (Stål)	1	0	1
Miridae H027	1	0	1
Neottiglossa undata (Say)	1	0	1
Rhyparochromidae H032	1	0	1
Salda sp.	1	0	1
Stictopleurus spp.	1	0	1
Tingidae	1	0	1
HYMENOPTERA			
Formicidae	1319	11	1330
Tenthredinidae	1	0	1
LEPIDOPTERA			
Moth	156	0	156
Gelechioidea	19	6	25
Lycaenidae	5	0	5
Anticarsia gemmatalis Hübner	2	0	2

Table B6. continued

Taxon [a]	Prairie [b]	Corn	Sum
LEPIDOPTERA			
Cisseps spp.	1	0	1
Lepidoptera Chrysalis	1	0	1
Parasitized caterpillar	1	0	1
Pieridae	1	0	1
Pterophoridae	1	0	1
ORTHOPTERA			
Oecanthinae	184	0	184
Conocephalini	131	0	131
Phaneropterinae	46	1	47
Nemobiinae	18	0	18
Oedipodinae	15	0	15
Copiphorini	12	0	12
Gomphocerinae	6	0	6
Conocephalinae	5	0	5
Tetrigidae	1	0	1
PSOCOPTERA	4	2	6
Grand total	21089	893	21982
Species richness (S)	194	48	198
Shannon's diversity index (H′)[f]	3.12	2.43	
Evenness (E)	0.59	0.63	
Percent similarity (S_{ij})			12.47%

[a] Seasonal abundance of incidental arthropods (not economically important pests of corn) calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of corn and summed across all sampling dates (once per month May through September in prairie; once per month June through August within corn) in 2010.

[b] Prairie and corn samples taken within STRIPs tresearch plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPs = Science-based Trials of Rowcrops Integrated with Prairies.

[c] Taxa accompanied by number and letter code are undetermined morphospecies.

[d] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for entire arthropod community, and morphospecies were not logged for the taxon.

[e] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[f] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B7. Pollinators sampled in prairie and soybean in 2009 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon[a]	Prairie[b]	Soybean	Sum
Halictidae[c]	142	9	151
Andrenidae	10	1	11
Hylaeus spp.	9	0	9
Megachilidae	9	0	9
Bombus spp.	8	0	8
Colletidae	8	0	8
Apis spp.	7	0	7
Apidae unknown[d]	12	0	12
Ceratina spp.	5	0	5
Stelis spp.	1	0	1
Grand total	211	10	221
Species richness (S)	10	2	10
Shannon's diversity index (H′)[e]	1.32	0.33	
Evenness (E)	0.57	0.47	
Percent similarity (S_{ij})			15.49%

[a] Seasonal abundance of pollinating Apoidea families and genera calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of corn and summed across all sampling dates (once per month May through September in prairie; once per month June through September within soybean) in 2009.

[b] Prairie and soybean samples taken within the STRIPs research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPs = Science-based Trials of Rowcrops Integrated with Prairies.

[c] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for the entire arthropod community, and morphospecies were not logged for the taxon.

[d] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[e] See methods for calculations of diversity indices (H′, E, and S_{ij}).

Table B8. Pollinators sampled in prairie and corn in 2010 from the STRIPs project sites at the NSNWR in Jasper County, Iowa.

Taxon[a]	Prairie[b]	Corn	Sum
Halictidae[c]	228	10	238
Apis spp.	32	0	32
Hylaeus spp.	23	0	23
Andrenidae	10	0	10
Ceratina spp.	10	0	10
Megachilidae	7	0	7
Bombus spp.	6	0	6
Colletidae	3	0	3
Apidae	2	0	2
Melissodes spp.	2	0	2
Apoidea unknown[d]	2	0	2
Grand total	325	10	335
Species richness (S)	11	1	11
Shannon's diversity index (H′)[e]	1.02	0.00	
Evenness (E)	0.42	0.00	
Percent similarity (S_{ij})			13.55%

[a] Seasonal abundance of pollinating Apoidea families and genera calculated as the total number collected in three sweep-net samples within each prairie strip or the fifth row of corn and summed across all sampling dates (once per month May through September in prairie; once per month June through August within corn) in 2010.

[b] Prairie and corn samples taken within the STRIPs research plots located at the Neal Smith National Wildlife Refuge in Jasper County, Iowa. STRIPs = Science-based Trials of Rowcrops Integrated with Prairies.

[c] Taxa (e.g., families, tribes) lacking 'unknown' designation were not identified below this taxonomic ranking for the entire arthropod community, and morphospecies were not logged for the taxon.

[d] Unknown denotes specimens that were not identified to a lower taxonomic ranking when time and appropriate keys were limited, or in the case of severely damaged specimens.

[e] See methods for calculations of diversity indices (H′, E, and S_{ij}).